

# National Safe \*T\* Propane

Explosion Resistant Safe \* T \* Cylinders CGX-4 Premium Propane

76979

January 25, 2000

Mr. Michael E. Dostert
FAA
Propulsion/Mechanical/Crashworthiness Branch (ANM-112)
Transport Airplane Directorate
Aircraft Certification Service
1601 Lind Avenue SW.

RE: Docket No. FAA-1999-6411 - 47

Renton, Washington 98055-4056

Dear Mr. Dostert:

This is the first time submitting anything to the FAA so please bear with me. My companies manufacture and sell propane Safe\*T\*Cylinders® with Safe\*T\*Foil® inside them. A Safe\*T\*Cylinder® is an explosion resistant fork lift cylinder. Over the years we were able to purchase the patents and develop a couple of extra ones on our own.

The rest of my presentation explains how our geometrically expanded aluminum mesh, passive, B.L.E.V.E explosion reduction system works, how it may help with Docket No. FAA-1999-6411, and the advantages this system may have over inert gasses and foam.

Again, if this is not in the form you are accustomed to please accept my apologies in advance. I really hope that your work with explosion technology can help people stay alive. I am a firm believer that pure science is good and what is invented in one field many times has applications in another area. This may be the case with Safe\*T\*Foil®.

Thank you in advance for your consideration of my ideas.

Thanks again:

George W. Kuhn

President

GWK:ps

cc: In duplicate

cf: c:\dd\faa\dostert1.doc

encls. Information about Safe\*T\*Foil®

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# How Safe\*T\*Foil® Can Prevent Ignition Sources From Being Present in Fuel Tanks When Failure Conditions Exist

Safe\*T\*Foil® simply prevents a flame front from forming. The mesh creates thousands, even millions of tiny little fuel tanks. In a flammable vapor the Safe\*T\*Foil does not allow the proper requirements for an explosion to form thereby preventing them.

You fill the fuel tank with Safe\*T\*Foil® and as the liquid fuel is used and vapors form the vapors are automatically in space that is filled with Safe\*T\*Foil® and if an ignition source is present the vapors do not explode because of the foil.

#### Maintenance Considerations of Fuel Tanks Containing Safe\*T\*Foil®

Maintenance of Safe\*T\*Foil® as it is currently used in Safe\*T\*Cylinders® is none. In an aircraft fuel tank situation it is my understanding that there are electrical lines, hydraulic lines, and other items passing through the fuel tanks and that these need to be inspected periodically.

Safe\*T\*Foil® can be in many shapes, sizes and/or configurations. You can have a solid non-removal bat. You can have ball shapes. You can have cigar shapes. If however, the solid Safe\*T\*Foil® forms were made in different sizes and/or shapes they could have wire handles on them and be color coded in such a way that they could be removed for inspections when needed and then put back in when the inspection is done.

On new aircraft the design of the fuel tanks could be improved so that not as many of the Safe\*T\*Foil® forms would have to be removed each time or even at all.

#### How Safe\*T\*Foil® Minimizes the Development of Flammable Vapors in Fuel Tanks

With Safe\*T\*Foil® the minimization of the development of flammable vapors in fuel tanks is just like the first requirement only stated in a different manner. The ignition sources can be there but the sources are rendered harmless be cause the ignition source can't make the vapors explode. In this requirement the flammable vapors can be in the tanks but the Safe\*T\*Foil® prevents the vapors from exploding.

#### **Environmental Concerns**

Aluminum is already used extensively in aircraft and the increased manufacture of aluminum would not have much of an impact. Safe\*T\*Foil® takes up between 2 and 3% of an the volume in a tank but doesn't really affect the fuel efficiency. Safe\*T\*Foil® does not retain any of the fuel so this is not a concern. There is a weight factor to be considered that would make fuel consumption greater because the aircraft would being heavier. This would have to be computed by your engineers because I have no readily available means of performing these calculations.

#### **Energy Concerns**

As per above the take-off weight of the aircraft would be heavier and therefore would use more fuel. This will have to be a decision made by the FAA on which method wastes the least amount of fuel.

#### Impact on Federalism

I can't see that these regulations would have any profound new effect on Federalism. As our society has evolved and become more complex there are some things that just have to be accomplished on the Federal level. Modifications in aircraft that effect the safety of the passengers and crews is one of those things.

#### **Economic Impact**

The economic impact of Safe\*T\*Foil® will have to be weighted against the value of human life. This is a question that society, and American society, has wrangled with and can never be completely resolved. My personal opinion is that making aircraft fuel tanks explosion resistant is like seat belts and air bags. I may seem costly at first but it creates jobs, creates creative thinking and saves lives.

#### Cost Estimates.

My cost to produce Safe\*T\*Foil® right now, ranges from \$2.50 to \$5.50 per gallon depending on the complexity and if the installation is an OEM type installation or a retrofit application. Testing has been completed by the Georgia Institute of Technology, the Illinois Institute of Technology and Packer Engineering. However, there would have to be a lot more testing done to get Safe\*T\*Foil® ready for aircraft use. There is also the issue of installing the foil.

The way I understand the way things are done on aircraft the Safe\*T\*Foil® would be manufactured to FAA specifications and then shipped to an airline. Once at the airline, under FAA guidelines, employees of the airline would then install and maintain the Safe\*T\*Foil®.

After everything got into place I feel a charge of \$1.00 per gallon of tank capacity by Safe\*T\*Foil® would be sufficient. I came up with this figure as follows:

In Docket No. FAA-1999-6411 you state that there are 6,000 aircraft that would be protected. If each aircraft has an average of fuel tank capacity of 2,000 gallons this would be a total of 12 million gallons protected. At a profit of \$1.00 per gallon this would be \$12,000,000.00 gross profit from which I would have to subtract already sunk costs. Then to protect these aircraft you would have to add in the maximum of \$5.50 per gallon for another \$66,000,000.00. The next part of the cost to the airlines of installing the

Safe\*T\*Foil® I have no idea. But if we take your figure of \$170,000,000.00 minus \$12,000,000.00 minus \$66,000,000.00 you are left with \$92,000.000.00. Divide this by 6,000 aircraft protected comes out to \$15,000.00 per aircraft to install the Safe\*T\*Foil®. If it took 5 men at \$50.00 per hour to protect the fuel tanks then they would have to be able to complete the task in 300 man ours or 60 hours per man. Based on my experience with inserting Safe\*T\*Foil® forms and retrofitting tanks with Safe\*T\*Foil® this is well within reason.

I also believe that after a learning curve has been taken advantage of, ordering Safe\*T\*Foil® in ever larger quantities and with the help of the FAA, the airlines and the aircraft manufacturers we could all work together to beat the \$170,000,000.00 FAA estimate.

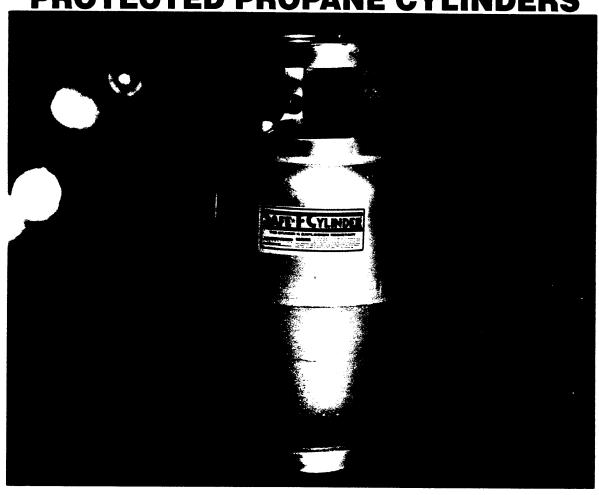
#### **Conclusions**

I hope that you will not allow the deficiencies in my presentation to dismiss Safe\*T\*Foil® out of hand for helping to make the fuel tanks safer. I have attached some copies of tests and the patent information on Safe\*T\*Foil®. If there is anything else I can do or if you would like me to come to Washington to talk with you about Safe\*T\*Foil® please let me know. I can also provide samples of Safe\*T\*Foil® with our latest patents incorporated if you would like. I have 13 years of information on Safe\*T\*Foil®. However, I know that you are very busy and probably have literally thousands of pages of information to digest on just Docket No. FAA-1999-6411 alone and I wanted to give you enough information so that if you thought Safe\*T\*Foil® might be the answer to the fuel tank problem we could proceed from here.

Please contact me if you have any questions or need more information.

# SAFE\* CYLINDER

PATENTED
EXPLOSION RESISTANT
PROTECTED PROPANE CYLINDERS



SAFE+T+FOIL

NEWEST SAFETY BREAK –
THROUGH IN THE 33 LB. CYLINDER MARKET!

# SAFE\*T\*FOIL PROTECTED LPG CYLINDER

#### SAFETY BREAKTHROUGH

The new SAFE-T-FOIL™ protected 4E D.O.T. cylinders are the state of the art in the storing and handling of propane.

#### PATENTED SYSTEM

National Safe \*T\* Propane is the licensee for all lift truck FOIL®technology in the U.S..

#### MINIMAL DISPLACEMENT

The matrix displaces less than 2% of the contents of the cylinder.

#### **DECREASED B.L.E.V.E.s**

# When exposed to fire, with . . . CYLINDER POSITION VERTICAL:

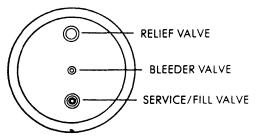
A two piece cylinder equipped with an aluminum cellular matrix exhibited a shorter time to boil-off than the standard two piece (4EW) cylinder.

#### CYLINDER POSITION HORIZONTAL:

A two piece cylinder equipped with an aluminum cellular matrix, when compared to the two piece unprotected (4EW) cylinder, exhibited a decrease in the tendency to B.L.E.V.E. (explode) or catastrophically fail and an increase in the probability of splitting.



#### **OPENINGS ON TOP**



# MODEL AL-1

33 LB. FORK LIFT TRUCK LIQUID WITHDRAWAL D.O.T. ALUMINUM CYLINDER

#### **DIMENSIONS**

Available Only Through Our Exclusive Sales Representative.

# Available from: National Safe \*T\* Propane

52 West Center Street Germantown, Ohio 45327 (513) 855-2081 1-800-551-3341

- Safe \*T\* Cylinders
- CGX-4 Propane Additive
- Safe \*T\* Tow Motor Certification
- Safe \*T\* School
- Safe \*T\* File

# United States Patent [19]

### Fenton et al.

[11] Patent Number:

4,673,098

[45] Date of Patent:

Jun. 16, 1987

[54]	FUEL TANK VAPORIZATION AND EXPLOSION RESISTANT APPARATUS		[56] References Cited U.S. PATENT DOCUMENTS				
[76]	Inventors: Ronald L. Fenton, 465 Dominion Dr., Apt. 1208, Wood Dale, Ill. 60191;		12/1967 Szego 4/1979 Szego				
		William C. Sames, 37W545 Mills Court, St. Charles, Ill. 60174	FOREIGN PATENT DOCUMENTS				
			8504128	2/1985 PCT Int'l Appl	220/88 A		
[21]	Appl. No.:	899,716	Primary Examiner—Edward G. Favors Attorney, Agent, or Firm—Douglas B. White				
[22]	Filed:	Aug. 25, 1986	[57]	ABSTRACT			
[51] [52] [58]	Int. Cl. <sup>4</sup>		There is provided a closed storage vessel having a hea conductive mesh-like interior affixed to the shell of th tank in secure heat conductive contact.  7 Claims, 1 Drawing Figure				

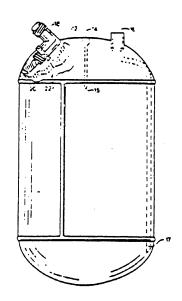
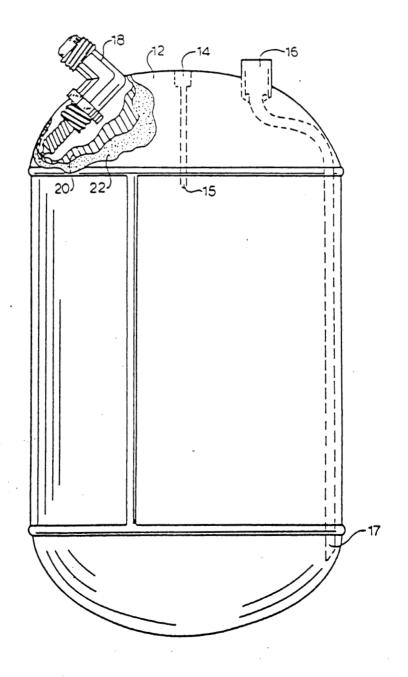


FIG. 1



#### FUEL TANK VAPORIZATION AND EXPLOSION RESISTANT APPARATUS

#### BACKGROUND OF THE INVENTION

The present invention relates generally to tanks for liquefied fuel gas such as propane or liquefied petroleum gas (LPG) and methods for controlling the temperature typical propane or LPG tank there is generally encountered a metallic tank member designed to contain the fuel under pressure and having a valve at one end to access the contents thereof. Typically, this tank is filled During normal operation the liquid fuel is vaporized under ambient heat to provide an operating pressure under which the vapor is withdrawn through the tank valve. As vapor is withdrawn the remaining liquid vaheat of vaporization. This causes the temperature of the remaining liquid to decrease, which in turn reduces the ability of the remaining liquid to vaporize. Conseresult of the declining liquid temperature due to withdrawal of the vapor. Since the heat loss due to the vaporization of the liquid must be replaced from the heat in the environment surrounding the container, the tank ture is raised.

In the case of fire, where heat is applied locally to the tank, the liquid proximate the hot spot will boil and increase the vapor pressure within the tank. This pressure relief valve and cause an explosion. Prior attempts to neutralize the explosion tendencies of the tank have included providing an expanded aluminum mesh within the tank, but this has been ineffective since it compresses during use and does not maintain conductive contact with the tank shell. Likewise, it will not enhance the vaporization under ambient conditions since heat is inefficiently conducted from the shell.

#### SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide an improved fuel tank which exhibits improved explosion protection while also improving the closed storage vessel having a heat conductive meshlike interior affixed to the shell of the tank in secure heat conductive contact:

Other objects and advantages of the invention will become apparent upon reading the following detailed 55 description and upon reference to the drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

fuel tank of the present invention.

While the invention will be described in connection with the preferred embodiment, it will be understood that it is not the intent to limit the invention to that embodiment. On the contrary, it is the intent to cover 65 all alternatives, modifications and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims.

#### DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1 there is shown a fuel tank of the 5 type usable with the preferred embodiment of the present invention having an outer enclosing member 12, and having affixed to its one extremity a dip pipe 14 arranged to detect the level of fuel in the tank when used in a horizontal manner, and having a fill/draw connecand vaporization of the liquid fuel within the tank. In s 10 tion 16 to provide access to the liquid fuel through the inner tank extension 17. In normal vertical operation, liquid stored in the tank vaporizes and accumulates in the uppermost portion of the tank whereupon it is withdrawn as needed through any standard connection (not substantially with propane or liquid petroleum gas. 15 shown) in the tank top. In conventional systems, the vaporization of the liquid is dependent upon the heat available from the external environment through the tank wall 12. Under periods of excessive use, the temperature of the liquid will be reduced to a point where porizes and in so doing absorbs heat known as the latent 20 this vaporization becomes limited which will in turn limit the amount of vaporized fuel available for consumption.

In accordance with the apparatus of the present invention, there is provided within the tank, and particuquently, the pressure of the system continues to fall as a 25 larly within the liquid filled portion of the tank, a heat conductive member 20 arranged to conduct heat from the external wall 12 of the tank member and distribute the heat throughout the liquid containing portion of the tank chamber. In the preferred embodiment of the preswill exhibit decreased function until the liquid tempera- 30 ent invention, this filler 20 would be formed as a metallic lattice shaped sheet rolled to conform to the confines of the tank and adhered to the tank shell by adhesive 22. Satisfactory results have been obtained with EC776 adhesive manufactured by 3M Corporation. This adhesure increase will quickly overwhelm any typical pres- 35 sive prevents separation of the metallic filler from the tank shell and ensures heat conductive contact.

In this arrangement the volume of the liquid filled portion of the tank is criss-crossed by numerous metallic foils. While the total volume of the tank is reduced to 40 some extent, considerable volume is retained by using thin foils in this lattice network.

. Technically, this apparatus increases the "wetted surface" of the tank. Generally, the greater the wetted surface of the tank, the greater the amount of vaporiza-45 tion capacity of the system. Consequently, a larger container, having a larger wetted surface area, would have a greater vaporizing capacity. By incorporating the apparatus of the present invention, providing the filler described above, an increase in the wetted surface efficiency and operation. Generally there is provided a 50 is achieved without changing the size or dimensions of the tank.

> Explosion protection is uniquely provided by this same system which improves vaporization. When a local hot spot occurs on the tank shell, the heat will dissipate through the liquid and localized boiling will be avoided. The adhesive contact of the filler to the tank allows dissipation of applied heat before the liquid temperature rises to a boiling condition.

In a further aspect of the present invention, there is FIG. 1 is an elevational view partially cut away of a 60 provided a relief valve 18 strategically positioned within said tank to provide its internal extremity at the uppermost portion of the tank when the tank is used in the horizontal mode. This ensures that the pressure relief valve accesses the vapor in all conditions and will not be covered by liquid fuel. When localized boiling does occur, the valve prevents tank explosion by releasing pressure.

We claim:

- 1. An improved tank apparatus for liquid fuel storage comprising:
  - a closed tank member having means for selective access to the contents of said tank; and
  - a heat conductive filler within said tank attached in 5 uration. heat conductive contact with said tank member for transmitting heat by conduction from said tank member to the liquid.
- 2. The tank apparatus of claim 1 wherein said heat ber by adhesive.
- 3. The tank apparatus of claim 2 wherein said heat conductive filler comprises a metallic foil member.

- 4. The tank apparatus of claim 3 wherein said metallic foil member forms a lattice configuration.
- 5. The tank apparatus of claim 3 wherein said metallic foil member is comprised of a rolled lattice sheet config-
- 6. The tank apparatus of claim 3 wherein said metallic foil member is comprised of multiple layers of a lattice sheet configuration.
- 7. The tank apparatus of claim 3 further comprising a conductive filler is affixed to portions of said tank mem- 10 pressure relief valve positioned at one side of said tank and having an internal extremity thereof projecting toward the uppermost portion of said tank.

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### United States Patent [19]

#### Fenton et al.

[11] Patent Number:

4,887,579

[45] Date of Patent:

Dec. 19, 1989

[54]	LP-GAS CARBURETION SYSTEM
	APPARATUS AND METHOD

[76] Inventors: Ronald L. Fenton, Wood Daie, Ill.; Robert Brandt, New York, N.Y.

[21] Appl. No.: 378,828

[22] Filed: Jul. 12, 1989

[56] References Cited

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 123/523

Primary Examiner—E. Rollins Cross

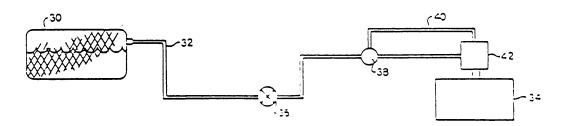
Attorney, Agent, or Firm-Dougles B. White

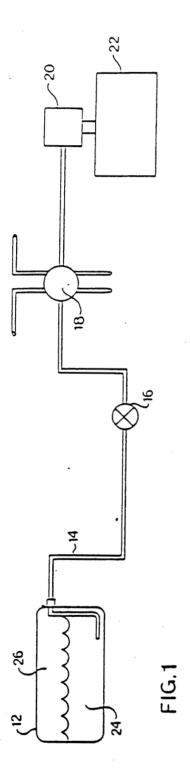
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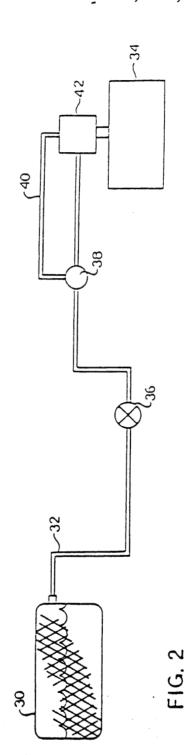
ABSTRACT

Generally there is provided a LPG fuel delivery system having a tank containing a thermally conductive mesh filler adhered to the tank walls by a thermally conductive adhesive. A vapor draw fuel line is fed from the tank to a pressure regulator and then to the carburetor of the engine. The tank apparatus mesh insert is a metal lattice formed from a thin aluminium sheet by a slitting process, where the slits are expanded to provide openings with transverse sides. When the sheet is rolled or combined with other sheets, it functions to thermally contact the adjacent layers and the tank walls. Ambient heat absorbed by the tank wall is tansferred through the adhesive to the filler and is distributed to the fuel to cause a consistant high vaporization and generate pressure.

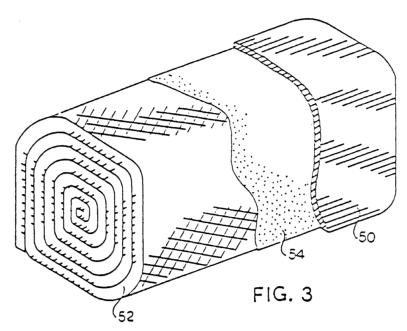
14 Claims, 2 Drawing Sheets







U.S. Patent Dec. 19, 1989 Sheet 2 of 2 4,887,579



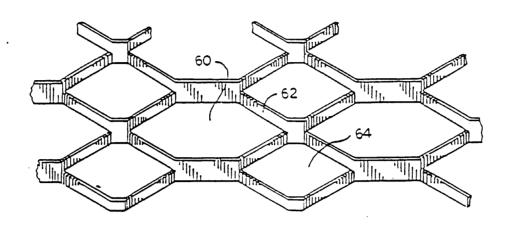


FIG. 4

#### LP-GAS CARBURETION SYSTEM APPARATUS AND METHOD

#### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

This invention relates generally to internal combustion engines and the carburetion and fuel systems required therefor. More particularly, this invention relates to improvements in the methods and apparatus for 10 the use of LP-Gas, such as propane, in internal combustion engines used with vehicles. Even more specifically, this new method and apparatus improves the ability of the fuel system to generate a vapor and maintain the requisite vapor pressure in a fuel line through improve- 15 ments in the tank design.

#### 2. Description of the Prior Art

LP-Gas (liquid petroleum gas) has been available and has been used as a fuel for internal combustion engines since the early 1900's, following the development of 20 propane and butane. LP-Gas vaporizes at a lower temperature than gasoline and is therefore handled differently; it is kept under a higher pressure, drawn from the tank as a liquid, and then vaporized prior to injection into the engine. Since LP-Gas vaporizes at a low tem- 25 perature this vaporization tendency has created quite a problem; as long as the low temperature and high pressure remain in balance, the fuel will remain a liquid. But when the pressure drops-such as when vapor is withdrawn or when fuel is withdrawn too rapidly—then the 30 remaining fuel boils and causes the temperature to drop, to "freeze" the fuel supply system. To help avoid this difficulty, the technique currently in use in LP-Gas systems is to withdraw the fuel as a liquid, maintain the fuel in the liquid state until reaching the engine vicinity, 35 and then vaporizing the fuel.

Because LPG fuel is clean burning a functional LPG system presents an attractive alternative to gasoline. In a gasoline system it is well known to withdraw the liquid fuel from the tank and then to create a fine mist at 40 the carburetor. Then typically the fuel will substantially, though not entirely, vaporize when entering the intake manifold. In this regard especially, propane has been considered superior because it will vaporize more aids is eliminated and it mixes well with air for a cleaner and more efficient combustion. The overall result, to the extent the propane system is feasible, is an environmentally preferred fuel.

they are designed with heavy gauge steel to withstand the high pressures. The usual propane system also employs a pressure relief valve, a manual shut-off valve on . the fuel line, a filler valve and guages. Since the fuel pump is used. The key to the prior systems, however, is the vaporizer-regulator. A good discussion of the vaporizer-regulator and the state of the art in LP-Gas fuel delivery systems is provided in the publication LP-GAS Association (NLPGA) located in Oakbrook, Ill.

The vaporizer-regulator used in LPG systems acts to vaporize the liquid fuel before directing it into the intake manifold. This device is used to avoid injecting the liquid drawn from the tank directly into the engine. 65 Drawing vapor, as an alternative, has been avoided as being unreliable since the vapor pressure varies greatly with the ambient conditions and drops quickly when

the vapor is drawn off, thereby rendering the system inoperative. And injecting liquid into the manifold has been avoided since it interferes with the engine operation. The prior 2rt solution is the location of a vaporizer 5 near the carburetor. This vaporizer is composed of a chamber into which the liquid fuel is fed under tank pressure and around which there are provided heating coils. Heated coolant from the engine cooling system is circulated through the coils to heat the chamber. Before entering the vaporizer chamber, however, the fuel is first passed through a pressure regulator to reduce the pressure to a value more acceptable to the engine-typically 10 psi-and such regulator may also employ a vacuum controlled fuel shutoff. Such a regulator is described in U.S. Pat. No. 2,775,981 and is available from Beam Products Mfg., Co.

Under cold operating conditions or high fuel demand requirements, the above described prior art apparatus will encounter a drop in fuel line pressure and a freezing of the fuel lines and of the system. This limit on the operability of the LPG system is partially responsible for its limited popularity; it limits the ambient temperatures in which it can be operated as well as limiting the size of the engine and power available. Moreover, the vaporizer device itself has contributed to the higher expense of the LPG system. Prior to the present invention no apparatus has been proposed for inexpensively vaporizing the LPG and eliminating the vaporizer device. Perhaps most importantly is that no apparatus has been proposed which allows for the high volume withdrawal of vapor from the tank without the risk of a critical pressure drop and a freeze up of the system.

#### SUMMARY OF THE INVENTION

Accordingly, it is a principal object and purpose of this invention to provide an improved LPG fuel system for internal combustion engines and particularly those used in vehicles.

It is a further and more specific object to provide such an improved system which functions to maintain the fuel vapor pressure at acceptable levels under a wide variety of fluctuating ambient conditions.

It is yet a further object of the present invention to easily and more completely. The need for cold starting 45 provide means for vaporizing the fuel without the use of an expensive vaporization device such as that which has been known to the prior art.

In yet a further advantage it is an object of the apparatus employed with the present invention to provide Propane fuel tanks differ from gasoline tanks in that 50 explosion supression characteristics while at the same time improving the thermal capabilities of the tank apparatus.

Generally there is described herein a LPG fuel system consisting of a tank having a thermally conductive system is maintained in a pressurized condition, no fuel 55 insert of a mesh material adhered to and thermally connected to the tank walls. This functions to draw the ambient heat from the side walls into the LPG fuel to cause vaporization at a higher rate for given ambient temperatures, to thereby maintain the vapor pressure in CARBURETION available from the National LP-Gas 60 the fuel line at a consistantly higher pressure. This vapor line is then fed to a pressure regulator, then to the air-fuel mixer (carburetor), and then to the intake manifold for combustion.

> The mesh insert of the tank apparatus employs, in the preferred embodiment, a metal lattice formed from a thin aluminium sheet by a slitting process in which an array of slits are arranged across the sheet. Once slit, the sheet is pulled to expand and to open the slits to thereby

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provide openings with transverse sides; and when combined with other sheets, or rolled, the lattice functions to thermally contact adjacent layers as well as the tank walls while only partially filling the tank void. The fuel in the tank circulates through the interstices of the lat- 5 tice where it is in contact with the thermally conductive mesh. Ambient heat is absorbed by the tank wall and transferred through a thermally conductive adhesive to the mesh insert where it is distributed to the fuel. Vapor under pressure is thereby made available to be drawn 10 off the top on demand and piped to the regulator without risk of loss of critical pressure or freeze-up of the

Other objects and advantages will become apparent upon reference to the drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of the prior art system employing the LPG fuel system for an internal combus- 20 tion engine. This drawing shows the prior art relation of the tank, the conduit for liquid draw, the vaporizerregulator, and the engine carburetor.

FIG. 2 is a block diagram of the apparatus, system with a thermally conductive insert adhered within the tank and providing a vapor draw conduit to a pressure regulator.

FIG. 3 depicts the tank of the present invention havlattice within the tank which is adhered to the walls of the tank by a thermally conductive adhesive.

FIG. 4 is a view of the lattice sheet of the mesh insert of the tank apparatus showing the plurality of varied sized openings in accordance with a further feature of 35 the invention.

While the invention will be described in connection with a preferred embodiment, it will be understood that it is not our intent to limit the invention to that specific all alternatives, modifications and equivalents as may be included within the spirit and scope of the invention as determined by the claims.

#### DESCRIPTION OF THE PREFERRED EMBODIMENT

Turning first to the prior art system shown in FIG. 1, there is depicted a LPG fuel system feeding liquid fuel from a tank 12, via a conduit 14, through a lock-off vaporized fuel is directed to the carburetor 20 and engine 22.

The tank 12 is shown in its usual configuration, having a partial volume of liquid 24 and a superimposed result of the surface evaporation of the fuel in the tank. and is dependent on the temperature of the fuel. This functions to pressurize the system and force liquid fuel to the vaporizer-regulator. When the fuel is withdrawn, limiting the volume demand that can be placed upon the system. Withdrawal of fuel at too high a rate causes the pressure to fall to a level at which the vaporizer-regulator will not receive enough fuel to allow normal operathe temperature of the remaining liquid fuel drops to an extremely low temperature. As a result the system becomes temporarily inoperative until the pressure and

temperature slowly rebuild. This fluctuation of the pressure and temperature is also responsible for the observed inability of the system to fully discharge the tank, since as the liquid level drops the propensity of the fuel to develop its vapor pressure declines.

The fuel system in accordance with the present invention is shown in FIG. 2 wherein a thermally absorbant tank 30 is employed to capture ambient heat and transmit this heat throughout the liquid fuel. As a result, a vapor is developed in the tank which is more consistant and dependable, and which doesn't fluctuate as radically with fuel withdrawal. The vapor is drawn off through conduit 32 and fed to the engine 34 through a manual or solenoid controlled lock-off valve 36 and a upon reading the following detailed description and 15 pressure regulator 38. This pressure regulator may be provided with a vacuum controlled shut-off through vacuum line 40 leading from the carburetor 42 back to the regulator in accordance with prior practice, to close the fuel line when the engine stops.

In accordance with the preferred embodiment of the invention there is shown in FIG. 3 a tank having side walls 50 and a thermal mesh insert 52. This insert is composed of a filler mass of a lattice construction which partially fills the volume of the tank while allowing and method of the present invention showing the tank 25 space within its interstices for the fuel. A roll or stack of these lattice sheets is then formed into the shape of the tank (FIG. 3) and the assembly is adhered to the tank walls with a thermally conductive adhesive 54. An adhesive known as EC776 available from 3M Corporaing a thermally conductive insert formed to provide a 30 tion has been used successfully and is resistant to degradation by the fuel. A more detailed description of this filler mass and the function of the thermal adherence is provided in U.S. Pat. No. 4,673,098 issued to on of the inventors herein.

The filler insert may be constructed of a slit sheet of thin metallic material, wherein the sheet is provided with an array of slits across its surface expandable into an array of openings 60 (FIG. 4). The expansion is accomplished by pulling the sheet at its periphery to open embodiment. On the contrary, it is our intent to cover 40 the slits into an array of diamond shaped openings. In such a lattice, transverse sides 62 are thereby created around the openings and are generally presented at an angled or inclined disposition relative to the apparent surface of the sheet. When such sheets are stacked or 45 rolled, they will invariably nest together and their effectiveness is dramatically reduced as a result. Some previous attempts at preventing such nesting have resulted in fan folded configurations and reversing of lavers; but the formation of such inserts are naturally expensive valve 16, to a vaporizer-regulator 18. From there the 50 and time consuming. In order to provide an economical yet effective anti-nesting technique, there is utilized herein a method of creating an array of slits and openings of varying size, such that the openings (and their inclined sides) will not "match up" when layered. This volume of vapor 26. This vapor is generated as a natural 55 may be accomplished by alternating various sized openings (60, 64), as shown, or creating a pseudo random array of multi-sized openings. In another version, dual sheets designed to be rolled or stacked together may be manufactured with one sheet having openings of one the pressure in the tank and in the fuel line drops, thus 60 size and the other sheet having openings of another size to thereby prevent the match up of the side walls of the openings.

From the foregoing description it will be apparent that modifications can be made to the apparatus and tion. At the same time the temperature of the tank and 65 method for using same without departing from the teachings of the present invention. Accordingly, the scope of the invention is only to be limited as necessitated by the accompanying claims.

We claim:

1. In a LPG fuel system for an internal combustion engine an improved fuel delivery apparatus comprising:

a tank member having thermally conductive walls and a thermally conductive filler insert in thermally conductive contact with said walls;

conduit means connected to said tank member for drawing vapor therefrom; and

a pressure regulator connected to said conduit means for receiving vapor from said tank member and 10 delivering vapor under a controlled pressure therefrom to the engine.

2. The fuel delivery apparatus of claim 1 wherein said thermally conductive filler insert comprises multiple layers of a metallic lattice sheet.

3. The fuel delivery apparatus of claim 1 wherein said thermally conductive insert is adhered to said tank walls.

4. The fuel delivery apparatus of claim 3 wherein said adhesive is thermally conductive.

5. The fuel delivery apparatus of claim 3 wherein said thermally conductive insert is comprised of a roll of a metallic lattice sheet.

6. The fuel delivery apparatus of claim 5 wherein said metallic lattice sheet presents an array of openings of a 25 plurality of sizes.

7. The fuel delivery apparatus of claim 6 wherein said metallic lattice sheet is formed by slitting said sheet and expanding the openings.

8. A vaporizing tank apparatus for a LPG fuel system 30 for an internal combustion engine comprising:

a tank member having thermally conductive walls;

a thermally conductive filler in thermally conductive contact with said tank walls, said filler having a thin lattice structure and formed to substantially con- 15 ings. form to the shape of the tank, wherein fuel is al-

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lowed to circulate within the interstices of the lattice; and

means for drawing vaporized fuel from said tank.

9. The vaporizing tank apparatus for a LPG fuel system for an internal combustion engine of claim 8 wherein said filler is comprised of multiple layers of a metallic lattice sheet.

10. The vaporizing tank apparatus for a LPG fuel system for an internal combustion engine of claim 9 wherein said thermally conductive filler is adhered to said tank walls with a thermally conductive adhesive.

11. The vaporizing tank apparatus for a LPG fuel system for an internal combustion engine of claim 10 wherein said metallic lattice sheet presents an array of openings of a plurality of sizes, and wherein said metallic lattice sheet is formed by slitting a thin foil sheet and expanding said slits into said openings.

12. A method of supplying vaporized LPG fuel to an engine comprising the steps of:

forming a thermally conductive filler from layers of metallic lattice sheet;

adhering said thermally conductive filler within a tank member having thermally conductive walls, said filler being arranged in thermally conductive relation with said walls;

drawing vaporized fuel from said tank.

13. The method of supplying vaporized LPG fuel to an engine of claim 12 wherein said filler is adhered to said tank walls with a thermally conductive adhesive.

14. The method of supplying vaporized LPG fuel to an engine of claim 13 wherein said metallic lattice sheet presents an array of openings of a plurality of sizes, and wherein said metallic lattice sheet is formed by slitting a thin foil sheet and expanding said slits into said openings.

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#### United States Patent [19] Fenton et al. FUEL TANK VAPORIZATION AND EXPLOSION RESISTANT APPARATUS AND IMPROVED FILLER MASS [75] Inventors: Ronald L. Fenton, Wood Dale, Ill.; Robert Brandt, New York, N.Y. [73] Assignee: Safetytech Corporation, Mount Prospect, Ill. [21] Appl. No.: 330,354 Mar. 28, 1989 [22] Filed: [51] Int. Cl.<sup>5</sup> ...... B65D 25/02 [52] U.S. Cl. ...... 220/88 A; 206/0.6 [58] Field of Search ...... 206/0.6, 0.7; 220/88 A, References Cited [56]

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958,944 5/1910 Steward ...... 220/88 A

3,356,256 12/1967 Szego ...... 220/88 R

4,925,053

[45] Date of Patent:

May 15, 1990

4,149,649	4/1979	Szego 220/88 A	
4,361,190	11/1982	Szego 220/88 A	
		Poschinger 206/0.6	
		Fenton et al 220/88 A	

Primary Examiner—Jimmy G. Foster Attorney, Agent, or Firm—Douglas B. White

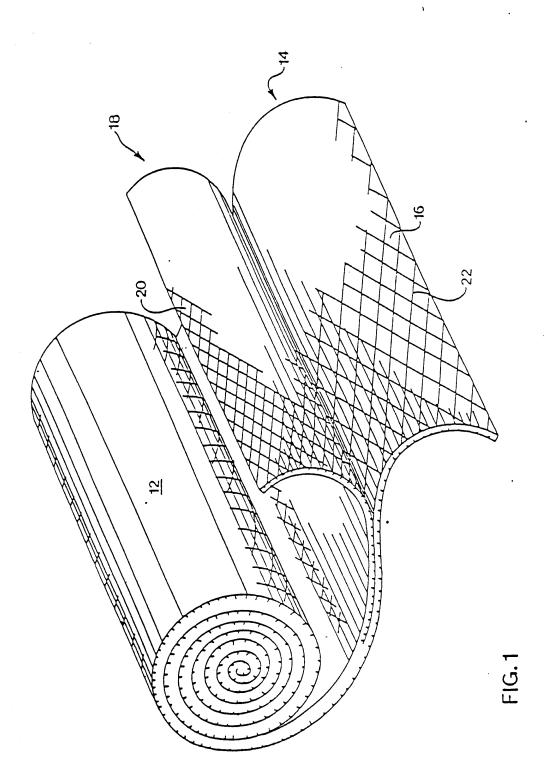
#### [57] ABSTRACT

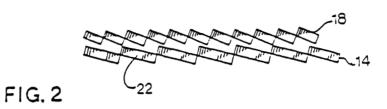
Generally there is provided an expanded foil sheet having an array of openings in a pattern exhibiting a plurality of dimension, which sheets are rolled or stacked, such that juxtaposed openings differ in dimension, to form a thermal filler mass for a tank. Alternatively, two or more foil sheets, each exhibiting openings or a pattern of openings of dimension differing from the openings of adjacent sheets are combined in a roll or stack to form the filler mass. Finally, in a further feature, the filler mass is adhered to the tank wall.

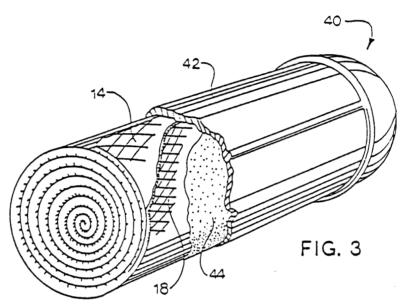
6 Claims, 2 Drawing Sheets

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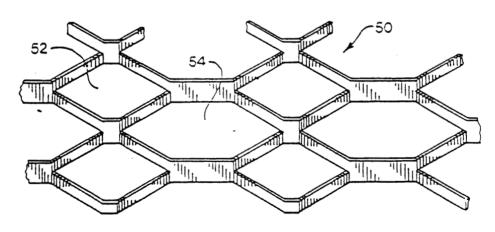


FIG. 4

#### FUEL TANK VAPORIZATION AND EXPLOSION RESISTANT APPARATUS AND IMPROVED FILLER MASS

#### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The present invention relates generally to tanks used for flammable or explosive fluids such as fuel tanks, ularly this invention relates to tanks employing a filler mass insert to aid thermal distribution to suppress explosion or to boost vaporization.

#### 2. Description of the Prior Art

In a typical tank application, such as a propane or 15 LPG tank, there is generally encountered a metallic tank wall designed to contain the fuel under pressure, with associated valves and connections at one end to access the contents thereof. During normal operation of a vaporization system the liquid fuel vaporizes in the 20 tank under ambient heat to provide an operating pressure under which the vapor is withdrawn through the tank valve. Consequently, the pressure of the system falls as a result of use and the tank will exhibit decreased function until the liquid temperature is raised.

Similarly, in liquid fuel applications, where heat is applied locally to the tank (such as in a fire), the liquid proximate the hot spot will boil and increase the vapor pressure within the tank and possibly ignite. Prior attempts to neutralize the explosion tendencies of the tank 30 have included providing an expanded aluminum foil mesh as a filler mass insert within the tank.

Improvements in filler mass design have been directed to preventing nesting of the mesh by reversing alternate layers in a roll. Nesting occurs where the mesh 35 pattern of adjacent layers settle against each other in a mating relation. This anti-nesting system is described in the 1979 patent issued to Szego, U.S. Pat. No. 4,149,649, as applied to explosion suppression in fuel tanks, although the technique had been employed for many 40 years prior in the filter industry. This filter application has been the principal use of such expanded foil. Even with the anti-nesting technique of Szego, the foil mesh collapsed and compressed during use and its effectiveness diminished. Recently, U.S. Pat. No. 4,673,098, 45 issued to Fenton et al., dramatically improved the thermal conductivity and reduced the compression tendency by using adhesive to secure the filler mass within the tank. Notwithstanding these developments the need continued to exist for the development of a filler mass 50 and tank apparatus design which would be more economical to manufacture, allow for greater fuel volume, and provide greater thermal distribution.

#### SUMMARY OF THE INVENTION

It is accordingly a principal objective of the present invention to provide a tank apparatus with a filler mass insert which causes a minimal reduction in tank volume;

It is a further objective to provide a filler mass for a fuel tank which doesn't nest, yet is economical to manu- 60

It is finally an objective of the improved filler mass insert to provide increased thermal transfer through better interstitial flow.

Generally there is provided in a first embodiment an 65 expanded foil sheet having slit formed openings of varying dimensions, which sheet is rolled or stacked to form a filler for a tank. In a second embodiment, two or more

foil sheets are formed, with each sheet having an array of openings but differing from one sheet to the next in the dimensions of the openings. These sheets would be rolled or stacked and inserted as a filler mass for a tank. Finally, in a further feature, the insert is adhered to the tank wall by use of a thermally conductive adhesive.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a roll of two sheets of including gasoline, diesel fuel, and LPG gas; and partic- 10 thermally conductive foil, each sheet having an array of openings but differing between them in the dimensions of the openings.

> FIG. 2 is a cross sectional view of the paired sheets of FIG. 1 showing the relationship of the foil sheets and the raised periphery of the openings.

> FIG. 3 is a perspective view of a tank apparatus employing the filler mass of FIG. 1.

> FIG. 4 is a perspective view of an alternative design of a single sheet of foil for use in the filler mass of the tank apparatus, said foil having an array of openings of various sizes thereon.

> While the invention will be described in connection with a preferred embodiment, it will be understood that we do not intend to limit the invention to that embodiment. On the contrary, we intend to cover all alternatives, modifications, and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims.

#### DESCRIPTION OF THE PREFERRED **EMBODIMENT**

Turning first to FIG. 1, there is shown the construction of a filler mass in accordance with the present invention for insertion within a tank as depicted in FIG. 3. This filler comprises a roll 12 of expanded foil mesh. The actual construction of this mesh is commonly known in the art and involves the placement of a plurality of slits in a sheet of thermally conductive foil, such as an aluminum foil, and the pulling of the sheet to expand the openings. In the manufacture of the sheet, an array of slits of predetermined dimension establish the dimension of the openings produced when the sheet is pulled and expanded.

In the first embodiment, a first sheet 14 is provided with spaced slits and thereby specifically dimensioned openings 16 when expanded. A second sheet 18 is similarly provided with spaced slits and resulting dimensioned openings 20 when expanded. When the foil is expanded, a peripheral edge 22 results and projects transversly to the plane of the sheet. (see FIGS. 2 and 4 for example). In accordance with the present invention. the openings 16 in the first sheet are designed to be larger or of a different shape than the openings 20 of the 55 second sheet. This results from the modification of the slit pattern when preparing the foil sheet. With this mismatch of dimension (size or shape), the second sheet 18 overlies the first sheet 14, as shown in FIG. 2 and, consequently, the sheets cannot nest into a mating relationship. As a result, the spacial separation of the two sheets is maintained when the sheets are combined into layers, yet the sheets do not need the further expensive processing of folding or reversing to accomplish the anti-nesting effect.

Once stacked or rolled, the filler mass is inserted into a container 40 (FIG. 4), such as a metal tank, having thermally conductive walls 42. The filler is adapted to conform to the container and is preferrably secured to

the walls by adhesive 44. Satisfactory results have been obtained with an adhesive known as EC 776 manufactured by 3M Corporation. This adhesive promotes thermal conduction, prevents separation of the filler mass from the container and resists the corresive action by 5 the tank contents.

In yet a further embodiment, the filler mass is manufactured from a single sheet 50, with an array of openings having differing dimensions arranged across the sheet. When the slits in the foil are arranged to generate regular diamond shaped openings as depicted, this provides a pattern of small and large sized openings 52 and 54, respectively, and provides a corresponding pattern other sheets, the relationship between adjacent layers is adjusted to juxtapose the differing dimensioned openings to avoid nesting.

With both embodiments due to the enlarged opening filler is increased with a resulting improvement in the efficiency of the apparatus. Moreover, the enlarged openings increase the available fuel volume and reduce the cost of materials and costs of manufacturing of the filler mass insert.

From the foregoing description, it will be apparent that modifications can be made to the apparatus and method for using same without departing from the teaching of the present invention. Accordingly the scope of the invention is only to be limited as necessitated by the accompanying claims.

We claim:

1. A thermally conductive filler mass insert for a container comprising multiple layers of thermally con- 35 sheet, said roll producing multiple layers of said sheet, ductive sheet, each of said layers having a plurality of slit formed openings defined therein, the periphery of said openings forming edges projecting transversely to the plane of said layer wherein said insert comprises a stack of interleaved layers, wherein each of said layers 40 exhibits an array of a plurality of openings in a pattern exhibiting a plurality of dimensions, said layers being arranged to juxtapose openings of differing dimension.

2. A thermally conductive filler mass insert for a container comprising multiple layers of thermally conductive sheet, each of said layers having a plurality of slit formed openings defined therein, the periphery of said openings forming edges projecting transversely to the plane of said layer wherein said insert comprises a roll of a single sheet, said roll producing multiple layers of said sheet, wherein each of said layers exhibits an array of a plurality of openings in a pattern exhibiting a 10 plurality of dimensions, and wherein said layers are arranged to juxtapose openings of differing dimensions.

3. A container of thermally responsive fluids comprising a thermally conductive container wall, a thermally conductive filler mass inert within said walls and in of projecting periphery. When coiled or stacked with 15 thermal contact therewith, said insert comprising multiple layers of thermally conductive sheet having slit formed openings therein, the periphery of said openings being arranged to project transversely to the plane of said sheet wherein each of said layers exhibits an array size in the combination, thermal convection through the 20 of a plurality of openings in a pattern exhibiting a plurality of dimensions, wherein said insert comprises a stack of interleaved layers, and wherein said layers are arranged to juxtapose openings of differing dimensions.

> 4. The container of claim 3 further comprising adhe-25 sive means for adhering said insert to said container wall.

 A container of thermally responsive fluids comprise. ing a thermally conductive container wall, a thermally conductive filler mass insert within said walls and in thermal contact therewith, said insert comprising multiple layers of thermally conductive sheet having slit formed openings therein, the periphery of said openings being arranged to project transversely to the plane of said sheet wherein said insert comprises a roll of a single wherein each of said layers exhibits an array of a plurality of openings in a pattern exhibiting a plurality of dimensions, and wherein said layers are arranged to juxtapose openings of differing dimension.

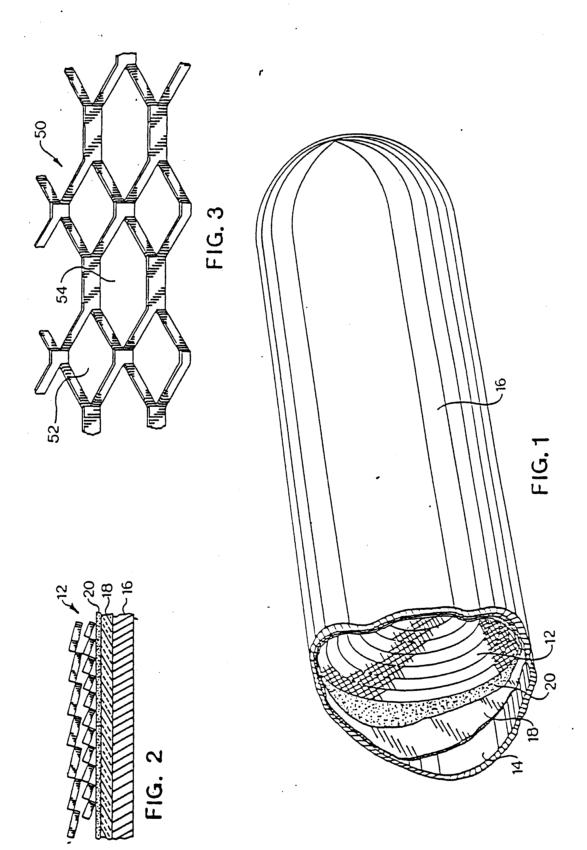
6. The container of claim 5 further comprising adhesive means for adhering said insert to said container

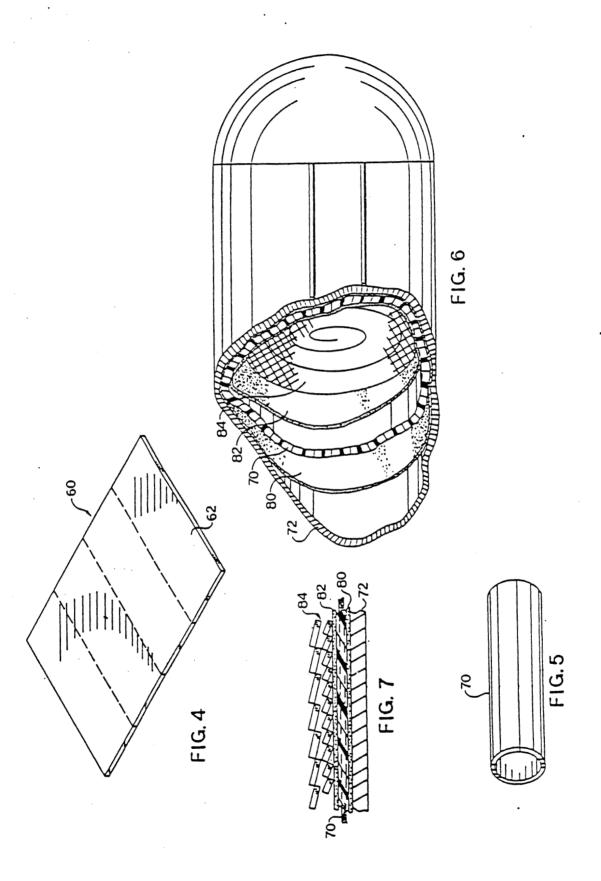
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United States Patent [19] Fenton et al.				[11]	Patent !	Number:	4,988,011	
			[45]		Date of	Patent:	Jan. 29, 1991	
[54]	EXPLOSION RESISTANT FUEL CONTAINER APPARATUS		3.951.718 4/1976 Gonzalez					
[75]	Inventors:	Ronald L. Fenton, Wood Dale, Ill.; Robert Brandt, New York, N.Y.	4,149.649       4/1979       Szego       220/88.4         4,230.758       10/1980       Nagai       220/45         4,581.285       4/1986       Mahefkey       220/45					
[73]	Assignee:	Safetytech Corporation, Mount Prospect, Ill.		4.615. 4.673. 4.765.	.098 6/1987	Fenton		
[21]	Appl. No.:	460,401		4,766,	420 8/1988	Hastings	220/453	
[22]	Filed:	Jan. 3, 1990	Primary Examiner—George E. LowTence Assistant Examiner—S. Castellano					
	Related U.S. Application Data			Attorney, Agent, or Firm-Douglas B. White				
[63]	[63] Continuation-in-part of Ser. No. 391,237, Aug. 9, 1989, abandoned.		[57]	)		ABSTRACT		
			Generally there is provided an exterior tank shell, typically of aluminum composition, having as an interior shell a layer of a stiff and strong material, such as aluminum oxide or a fiber/resin composite, applied to the inside surface of the shell. A thermally conductive mesh					
[51] [52]	·							
[58]								
[56]	6] References Cited		filler insert is fitted within the tank and secured to the inner shell layer with adhesive.					
	U.S. PATENT DOCUMENTS							

8 Claims, 2 Drawing Sheets

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#### EXPLOSION RESISTANT FUEL CONTAINER APPARATUS

This application is a continuation-in-part of Ser. No. 5 07/391,237, filed Aug. 9, 1989, now abandoned.

#### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The present invention relates generally to fuel tanks 10 used for flammable or explosive fluids such as gasoline, diesel fuel, and LP-Gas; and more particularly this invention relates to tanks employing thermal distribution to suppress explosion. This invention further relates to improvements in such apparatus for use with light- 15 weight transportable tanks, and more precisely with aluminum tanks, which tend to lose structural integrity under high heat.

#### 2. Description of the Prior Art

In a LP-Gas fuel tank application there is generally 20 provided a metallic tank wall designed to contain the fuel under pressure. This tank is typically of steel composition for stationary applications and further includes associated valves and connections at one end for access to the contents thereof. When the tank is in a heated 25 secure the mesh insert to the inner shell layer. environment, such as in a fire, the liquid proximate the hot spot will boil and eventually ignite, with a resulting explosion. Prior attempts to neutralize the explosion tendencies of the tank have included providing an expanded aluminum foil mesh as a filler mass insert within 30 employing a filler insert secured therein. the tank. Such a system is described in Canadian Patent No. 736,802. The container is filled with a mesh which divides the container into many small cell-like compartments, and through thermal contact with the mesh the fuel transfers the heat away from the "hot spot" to 35 tus, showing an array of openings of various sizes. delay the local rise in temperature—and delay the explosion.

Improvements in tank design have recently been directed to preventing nesting of the mesh insert by reversing alternate layers in a roll. Nesting occurs 40 where the mesh pattern of adjacent layers settle against each other in a mating relation. A recent anti-nesting system is described in U.S. Pat. No. 4,149,649. Even with the anti-nesting technique of the prior art, the lightweight foil of the mesh tended to collapse and 45 compress and its effectiveness diminished during use; this is particularly true for transportable containers, and vehicular fuel tanks. Recently a new technique described in U.S. Pat. No. 4,673,098, issued to Fenton and reduced the compression effect. This method used a thermally conductive adhesive to secure the filler mass within the tank. This kept the filler structure intact and yet facilitated the thermal transfer to the liquid from the adjoining tank surface.

In the vehicle tank industry and in the design of transportable tanks, weight is of high importance and tanks of aluminum composition have been utilitzed. Unfortunately, the aluminum tank wall tends to melt at such a lost in a fire. Attempts to insulate or coat the outer surface of such tanks have proved satisfactory inasmuch as the coating does not remain sufficiently intact to produce reliable results.

#### SUMMARY OF THE INVENTION

It is accordingly a principal object fo the present invention to provide an explosion suppression tank ap-

paratus with a filler mass insert which is functional with transportable containers and vehicle tanks.

It is a further object of the invention to provide such a tank apparatus with a filler mass for a fuel tank which prevents nesting, provides increased thermal transfer through better interstitial flow, but yet is economical to manufacture.

It is finally an object of the present invention to provide a lightweight internal shell layer which in one aspect exhibits thermal transfer to delay explosion in a fire but also temporarily contains the fuel during limited failure of the outer shell.

Generally there is provided an outer shell, typically of aluminum composition, having an inner shell composed of a layer of strong, stiff and thermally conductive material adhered to the inside surface of the outer shell. The inner shell layer may be an aluminum oxide layer or of a hydrocarbon compatible fiber and resin composite. In one embodiment a layer of thermally conductive adhesive is applied on the inner surface of the inner shell and a mesh insert is fitted within and secured to the inner shell with the adhesive. In another embodiment the resin of the fiber/resin composite acts to adhere the inner shell layer to the outer wall and to

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partially cut-away perspective view of the tank apparatus in accordance with the present invention

FIG. 2 is a cross sectional view of the layers of FIG. 1 proximate the tank wall.

FIG. 3 is a perspective view of a sheet of expanded foil used in forming the filler insert of the tank appara-

FIG. 4 is a perspective view of a sheet of a hydrocarbon compatible composite.

FIG. 5 is a perspective view of a section of the sheet of FIG. 4 cut and formed to fit within the tank.

FIG. 6 is a cut-away perspective of the tank employing an inner shell layer formed with a fiber and resin composite.

FIG. 7 is a cross-sectional view of the wall portion of the tank of FIG. 6.

While the invention will be described in connection with a preferred embodiment, it will be understood that we do not intend to limit the invention to that embodiment. On the contrary, we intend to cover all alternatives, modifications, and equivalents as may be included et.al., dramatically improved the thermal conductivity 50 within the spirit and scope of the invention as defined by the appaended claims.

#### DESCRIPTION OF THE PREFERRED **EMBODIMENT**

Turning first to FIG. 1 there is shown a tank constructed in accordance with the present invention having a thermal mass 12 of expanded foil mesh positioned within the tank. The actual construction of the mesh insert is well known in the art and involves the placelow temperature that its structural integrity is quickly 60 ment of a plurality of slits in a sheet of thermally conductive foil, such as an aluminum foil, and then pulling of the sheet to expand the openings. In the manufacture of the sheet, an array of slits of predetermined dimension establish the size and shape of the openings pro-65 duced when the sheet is pulled and expanded.

> In one embodiment of the tank construction of the present invention, the structural outer shell (forming the primary container wall) is manufactured in accordance

with commonly known tank manufacturing techniques and the interior sufrace 14 of the tank outer shell 16 is provided with a thin, yet stiff, inner shell 18 (forming a secondary container wall). This inner shell is (in one embodiment) a coating of a type which is easily applied 5 and when in service is resistant to deterioration by hydrocarbons. Preferably this material is of high thermal conductivity, and is applied in a spray, similar to a paint application. An aluminum oxide spray accomplishes these purposes and produces an effective layer having a 10 bon compatible fiber and resin composite. Such a comfinished thickness in the range of 1/16th of an inch or less (greater thickness is acceptable where weight is less critical). The dried coating presents a stiff thermally conductive layer which forms an inner shell and is adhered to the outer aluminum shell.

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The physical characteristics of this layer is such that it begins to lose its structural integrity at a temperature which is higher than the temperature at which the outer aluminum shell begins to lose its structural integrity (melting temperature).

Overlying the inner surface of the interior shell there is provided a layer of adhesive 20. The formed filler insert 12 having interstitial openings throughout is secured within the inner shell by adhesive. This adhesive is chosen for qualities of both thermal transfer and hy- 25 drocarbon resistance, and satisfactory results have been obtained with an adhesive known as EC 776 manufactured by the 3M Corporation.

As best seen in FIG. 2 the filler 12 is secured along its outer surface to the inner shell coating 20 to form an 30 internal reinforcement to the thin inner shell. The unique function of this apparatus in a high heat environment is determined by this combination of shells of differing melting temperatures. As the tmeperature around the tank rises, the tank absorbs the heat in its 35 outer shell in the first instance. As the temperature of a localized portion of the lightweight aluminum outer shell rises, the inner shell proximate to that hot spot heats up but also transfers heat laterally throughout the inner shell layer as well as vertically to the interior of 40 cured by the addition of heat to the tank assembly. the tank through the filler insert. To the extent that heat is transferred through the inner and outer shells, the adhesive and the mesh insert carry the heat to the remainder of the tank. As temperatures continue to elemelting temperature, the inner shell continues to remain intact due to its higher melting temperature. This fragile inner shell, using the adhered mesh insert as structural support, functions to temporarily resist the high internapressures encountered during the failure of the outer 10 shell.

Production of the filler mesh insert of the present invention is accomplished (according to methods well known in the art) by forming it from a flat sheet not shown) which is provided with spaced precisely cimen- 15 sioned siits. The periphery of the sheet is then pulled to expand the openings to produce the expanded sheet of FIG. 3. Rolling or stacking of the expanded sheet forms the filler insert for the tank. In order to prevent nesting of the neighboring layers of the expanded sheet, a sheet 60 50 is formed with a array of formed openings of differing dimensions (a pattern of small 52 and large 54 openings). This sheet, or multiple sheets, may then be rolled or stacked together, such that adjacent openings do not match-up; the transverse edges surrounding the open- 65 ings interfere with one another to prevent nesting. Another version of the above consists of interleaved layers of sheets with each sheet having uniform openings but

adjacent sheets having openings of differing size. A first layer includes a sheet presenting openings of one size and an adjacent layer sheet presenting openings of a second size. With the above anti-nesting techniques. larger openings are formable within the tank mesh to increase fuel capacity while maintaining effective thermal function and structural support.

In a second embodiment of the invention shown in FIGS. 4-7, the inner shell is formed from a hydrocarposite may consist of fiberglass and epoxy resin. This formed according to methods well known in the fi-. ber/resin industry into a cylindrical shape the size of the inside of the outer shell.

In one method of forming the fiber/resin composite shell, a portion of a cured sheet of 60 fiber cloth impregnated with resin is severed into a section 62 of desired dimension and bent to form a cylinder 70 for insertion into the outer shell 72. An achesive 80 is applied to the inside of the outer shell and the fiber and resin composite is adhered therein to form an inner shell layer. As before, the inside surface of this inner shell layer is coated with adhesive 82 and the mesh insert 84, formed to fit the tank as described above, is secured therein.

In another of said methods, a roll of uncured resin impregnated fiber cloth is severed in suit able lengths and formed to the inside diameter of the tank. The cylinder is cured in this configuration and adhered to the inside of the tank as described above. The mesh insert is also adhered to the adhesive coated inner shell layer in the same manner.

In another technique, the uncured fiber cloth/resin composite is fitted within the tank and the resin on the surface of the composite used as the adhesive to secure the inner shell layer to the outer shell. Likewise, the inner resinous surface of the composite will serve as the adhesive to adhere the mesh insert within the tank. The composite and the adhesive/resin surfaces are then

Another method known in the art employs a mix of resin and chopped fibers which are sprayed onto the inner surface of the outer shell. In such a technique, the outer shell is coated on its inner surface by a layer of the vate and where the outer shell approaches its ontical 45 liber/resin composite. The filler mesh is then inserted as described above. Application of heat cures the resin and acheres the filler mesh and the inner shell within the cuter shell.

> In yet a further aspect to the invention the interfacing aver 20 functions as an expendable ablative in the event nigh heat. Such a layer exudes a gas or vapor at high reat conditions to displace any fuel which may be proxmate the layer. This enhances the explosion protection by preventing contact of the fuel with the hot shell ayers. In practice the EC776 adhesive which secures the mesh insert to the inner layer, functions as such an expendable ablative.

> From the foregoing description it will be apparent that modifications can be made to the apparatus and method for using same without departing from the teaching of the present invention. Accordingly the scope of the invention is to be limited only as necessitated by the accompanying claims.

We claim:

1. An explosion resistant container for inflammable fluids comprising:

an outer shell forming a primary wall of the container

an inner shell affixed within said outer shell to provide a secondary wall of the container;

wherein, the temperature at which said inner shell begins to lose its structural integrity is higher than the corresponding temperature of said outer shell; 5 and

a filler insert formed to substantially conform to the shape of the container and adhered to said inner shell.

2. The explosion resistant container of claim 1 10 wherein said inner shell is comprised of a layer of aluminum oxide.

3. The explosion resistant container of claim 2 wherein said filler insert is comprised of multiple layers of thermally conductive sheet having formed openings 15 of differing dimensions in each layer thereof, wherein adjacent layers of said sheet are arranged such that said formed openings of differing dimension are juxtaposed.

4. The explosion resistant container of claim 3 wherein said multiple layers of thermally conductive 20 sheet are formed from a rolled sheet of expanded metallic foil having said formed openings of differing dimensions, wherein said openings of differing dimensions are

juxtapose when said sheet is rolled to form said filler insert.

5. The explosion resistant container of claim 1 wherein said inner shell is comprised of a hydrocarbon compatible fiber and resin composite.

6. The explosion resistant container of claim 5 wherein said filler insert is comprised of multiple layers of thermally conductive sheet having formed openings of differing dimensions in each layer thereof, wherein adjacent layers of said sheet are arranged such that said formed openings of differing dimension are juxtaposed.

7. The explosion resistant container of claim 6 wherein said multiple layers of thermally conductive sheet are formed from a rolled sheet of expanded metallic foil having said formed openings of differing dimensions, wherein said openings of differing dimension are juxtapose when said sheet is rolled to form said filler insert.

8. The explosion resistant container of claim 1 further comprising an expendable ablative interposed between said filler insert and said inner shell.

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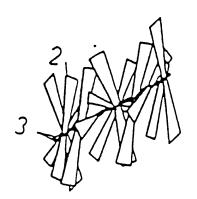
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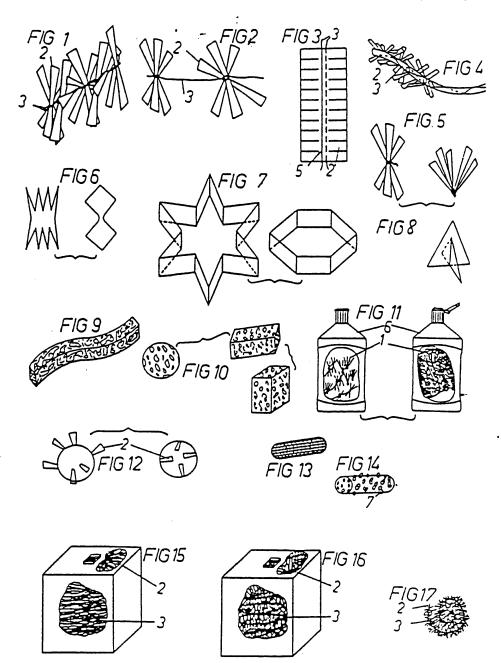
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Lichka			[45]	Date of	Patent:	May 22, 1990	
[54]	SYSTEM OF SAFETY TANK ELEMENTS PREVENTING EXPLOSIONS		3,322,294 5/1967 Nemeth				
[75]	Inventor:	Helmut J. Lichka, Vienna, Austria	3,650,			220/88 R	
[73]	Assignee:	Technolizenz Establishment, Triesen, Liechtenstein	3,708, 3,822, 3,979.	807 7/1974	MacDonald e	220/88 R X t al 220/88 R l 220/5 A X	
[21]	Appl. No.:	289,481	4,013,		Wiggins et al.	220/88 R X	
[22]	Filed:	Dec. 21, 1988	4,134, 4,248, 4,294,		King et al	220/88 R X 220/88 R X 220/85 S X	
	Related U.S. Application Data  [63] Continuation of Ser. No. 713,727, filed as PCT AT 84/00022 on Jun. 18, 1984, published as WO85/00113 on Jan. 17, 1985, abandoned.		4,566,		Poschinger	220/88 R X	
[63]			4,613,054 9/1986 Schrenk				
[30]	Foreig	Application Priority Data	[57]		ABSTRACT		
	Jun. 27, 1983 [AT]       Austria       2342/83         [51]       Int. CL <sup>5</sup> B65D 25/00         [52]       U.S. Cl.       220/88 R         [58]       Field of Search       220/88 R, 85 S, 5 A			Explosion-preventing tank safety elements (TSE) are provided for filling containers for explosible fluid and gas media while avoiding enlarging, transforming, cutting or welding the tanks. The loading of the elements is possible simply through the filling pipe or outlet opening of each container.			
	2,305,923 12/1942 Held			21 Claims, 1 Drawing Sheet			

United States Patent [19] [11] Patent Number: 4,927,045





#### SYSTEM OF SAFETY TANK ELEMENTS PREVENTING EXPLOSIONS

This application is a continuation of U.S. Ser. No. 713,727, filed as PCT AT84/00022 on Jun. 18, 1984, 5 published as WO85/00113 on Jan. 17, 1985, now aban-

#### FIELD OF THE INVENTION

The invention relates to full elements for containers for explosible fluids which have at least one inlet or 10 outlet opening, for the creation of a heat-conducting or electrically conducting structure in space.

#### BACKGROUND OF THE INVENTION

Particularly from U.S. Pat. No. 3,356,256, the sugges- 15 tion has become known to include in containers for explosible fluids a spatial metal grid which prevents local overheating by rapidly conducting away heat and thus making the container explosion-proof. In the known device, the needed grid is constructed of layers 20 of metal mesh rolled up like balls of cloth and introduced during the manufacture of the tank into same. The necessity to provide the tank with an explosionproof safety device or, however, to cut it open to insert the metal grid and to then re-assemble it has the result 25 that the mentioned suggestion was hardly practical so far. Mainly, it was not possible to protect gas containers or gas bottles against explosions by a heat-conducting. spacial metal grid, since here an insertion of the grid during the manufacture would be difficult and a subse- 30 quent insertion would not at all be permissible due to the partial destruction of the container.

#### SUMMARY OF THE INVENTION

The primary goal of the invention is to make all types 35 of containers for explosible liquids or gases explosionproof without opening or even removing the container, for example without removing it from a vehicle.

This goal is achieved by the dimensions of the fill elements exceeding in at most one direction the diame- 40 ter of the largest opening of the container. In this manner, it is possible to insert the fill elements subsequently into the finished container, which thus represents the basic concept of the invention.

The inventive fill elements can be made of various 45 materials which on one hand assure a quick heat conduction or electrostatic conduction and on the other hand give the elements a structure which makes it possible to divide the tank interior into small areas with only a slight loss of usable volume.

Aside from aluminum, in particular anodized aluminum, stainless steel or tin foil can be used; for the better chemical stabilization it is possible to coat these metals with galvanic layers. However, it is also possible to use their conductivity is increased sufficiently, for example by adding graphite.

The plastic parts can thereby be produced by injection molding, cutting, casting or stamping techniques.

be used for carrying out the concept of the invention. The elements, which are inserted through the inlet or outlet opening of the container, which remains installed, must occupy at least the whole free gas volume of the tank, and thus not be appreciably compressed 65 under the influence of movements of the tank contents and of fill elements which lie thereabove. On the other hand, adjacent fill elements must touch each other

along their adjacent portions at sufficiently many places so that there does not occur an interruption of the heat conduction or electrical conduction and thus a reduced explosion protection.

In spite of the principally existing possibility to construct the fill elements totally different, it is particularly advantageous if the fill elements are provided with a plurality of diverging plates. It is possible in this case to insert the brushlike fill elements through an inlet opening, even if they have to be compressed temporarily during the insertion. This is particularly important during the loading of gas containers with a narrow opening. The platelike fill elements assume again their original shape inside of the container; they penetrate through one another in their areas close to the surface, whereby their mutual approach is limited to the necessary degree. In particular, for cube-shaped containers, it is possible to introduce a single large brushlike cell utilizing its elasticity, which then fills the entire container interior. It is easily possible to achieve on the one hand by, adjusting the number and dimension of the plates, the necessary heat bridges or electrically conducting chains between the fill elements, while on the other hand the total liquid or gas volume which is displaced by the fill elements remains in the order of magnitude of approximately 1.7%-3% of the container volume.

Rolling movements due to mass inertia are suppressed by the elements.

Even though the use of fill elements with diverging bunches of plates is advantageous, in that such dry cells can be introduced through inlet openings which can only be passed through deformation of the bunches, other cell shapes can by all means also be used according to the invention. In as far as metal elements are used, particular attention was given here to shape these through a suitable folding, which on the one hand assures mutual contact of the elements at as many points as possible, and on the other hand prevents their collapsing at the bottom of the container. The number of geometrical shapes which are possible in this sense is practically unlimited, since thin metal plates can be connected with one another, nested into one another. folded in a zig-zag shape, or constructed spiral-shaped. Also, spherical shapes which are created by forming balls of foil can be used, as long as the foil is sufficiently perforated in order not to prevent the filling of the container with fluid.

An important additional difference relates to whether 50 the fill elements are introduced into the container as individual pieces or in continuous strips. If the elements consist substantially of a plastic foam, they will generally be inserted in the form of small balls or cubes. Whereas, in particular, the previously mentioned plastics like polyurethane or polysulphone as long as 55 bunches of plates are arranged in a practical manner on one or several wires and are introduced on same continuously into the container.

For example, the safety element which is based on a center axis formed by one or two wires can be produced Basically, many different shapes of fill elements can 60 in such a size that the introduction of only one large element is sufficient to ensure the safety of a fuel tank, tanker, etc. This has up to now the unrivalled advantage that the large elements can subsequently be removed quickly and easily from the tank, which is important for the cleaning of the tank.

In addition, by varying the size of the elements, custom-made and inexpensive solutions to problems can be achieved.

#### MIL-B - 87162 (USAF)

#### 3. REQUIREMENTS

- 3.1 Qualification. The material furnished under this specification shall be a product which is qualified for listing on the applicable qualified products list at the time set for opening of bids.
- 3.1.1 Requalification. Before any change is made in the composition or fabrication process of the final product, the contractor or manufacturer shall contact the qualifying activity to determine if requalification is required.
- 3.2 Materials. The aluminum alloy foil used in producing the expanded metal mesh shall conform to the Aluminum Association, Incorporated 3003 H24 or 3010 H24. The Grade 1 foil shall be untreated. The Grade 2 foil shall be coated with a chromate conversion coating conforming to MIL-C-5541. The foil shall be slit longitudinally such that the resultant web, whenexpanded laterally forms a mesh of hexagonally shaped openings. The expanded foil shall be folded to form a batt having small contiguous apertures. The product supplied under this specification shall be of the same quality and manufacturing process as that used in the qualification samples. The end product shall be expanded mesh which is suitable for use in aircraft fuel tanks to suppress pressure build up and explosions due to ignition of vapor/air mixtures.
- 3.3 <u>Physical properties and characteristics</u>. The physical properties and characteristics of the suppression material shall be in accordance with Table I.
- 3.4 <u>Combustion overpressure (Explosion Suppression)</u>. The combustion overpressure shall be as follows:
  - Type I: Maximum combustion pressure increase shall not exceed 20 psi when combustion volume (Vc) = 5 Volume Percent:

    Initial Pressure (Ip) = 3 psig.
  - Type II: Class A; Combustion pressure increase shall not exceed 20 psi when Vc = 5 Volume Percent and Ip = 3 psig.
    - Class B: Combustion pressure increase shall not exceed 15 psi when Vc = 10 Volume Percent and IP = 3 psig.
  - Type III: Class A: Combustion pressure increase shall not exceed 18 psi when Vc = 10 Volume Percent and Ip = 3 psig.
    - Class B: Combustion pressure increase shall not exceed 15 psi when Vc = 10 Volume Percent and Ip = 3 psig.
- 3.5 Slosh testing. Slosh testing in accordance with 4.4.1.9 and 4.4.1.10 respectively, shall be conducted on tanks packed with the explosion suppression material. At the end of each test the batts of material shall be

#### MIL-B-87162 (USAF)

carefully removed for inspection. The physical integrity of the batts shall be maintained and batts should not shrink more than 2 percent in any dimension. Total suppression material breakdown in any of the tests shall not exceed 0.3 percent by weight of the total material installed. Abrasion to tank coating and sealant materials shall be minimal and the effect not be detrimental to the normal operation of the fuel system. Any abrasion to the tank wall should not be significant enough to have an adverse influence on the fuel tanks performance.

- 3.6 Dimensions and tolerances.
- 3.6.1 Standard batt size. Unless otherwize specified, suppression material shall be produced in standard size batts of the size,  $36 \times 22 \times 12$  inches (91.4 x 55.8 x 30.5 cm).
- 3.6.2 Optional batt sizes. When specified, batt sizes shall be made with the following maximum dimensions:

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Type I: 37 \times 36 \times 18 inches (94 x 91.4 x 45.7 cm)
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Type II: Class A: 42 x 36 x 18 inches (106.7 x 91.4 x 45.7 cm) Class B: 38 x 36 x 18 inches (96.5 x 91.4 x 45.7 cm)

Type III:Class A: 44 x 36 x 18 inches (111.7 x 91.4 x 45.7 cm)
Class B: 39 x 36 x 18 inches (99 x 91.4 x 45.7 cm)

3.6.3 Tolerances. Production tolerance limits on standard and optional batt sizes shall be as follows (See 6.3):

Length: +1, -0 inches (+2.54, -0 cm)
Width: + 1/4 inches (+ 0.64 cm)
Thickness: +1.8 inches (+ 0.32 cm)

- 3.7 Identification of Product. The suppression material shall be sealed in a clean polyethylene bag as it comes off the production line. A labeled card shall be provided inside the bag which clearly identifies the manufacturer's part number, date of manufacture, production run number, batt number and size. When applicable, the government contract or order number shall be included. There shall be no color coding or marking on the batt surface.
- **3.8** Workmanship. The suppression material shall be fabricated in accordance with high-grade manufacturing practices covering this type of material. The material shall be suitable for its intended use and free of defects which may affect its performance. It shall be of a uniform appearance and free from tears.

#### 4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection. Unless otherwise specified in the contract or purchase order, the contractor is responsible for the performance



IITRI Final Report CO8999 6 April 1989

# EXPLOSION SUPPRESSION TESTING OF SAFETY GUARD SAFE-T-FOIL IN MARINE GASOLINE CANS

Prepared for

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Attention: Mr. Ronald Fenton

Prepared by

Mr. Ronald Pape III Research Institute 10 West 35th Street Chicago, Illinois 60616 **FOREWORD** 

This is the final report for an experimental study of the protection afforded by the Safety Guard Corporation Safe-T-Foil material used in marine gasoline cans. The tests that were conducted demonstrated that Safe-T-Foil significantly reduces or eliminates the explosion hazard of marine gasoline cans exposed to a sustained external fire such as from a gasoline spill. The tests also demonstrated that Safe-T-Foil significantly reduces or eliminates the potential for explosion of the marine gasoline cans tested when penetrated by a ballistic incendiary round. IITRI staff participating in the testing included Carl Foxx and Richard Joyce. Ronald Pape provided support in test planning and documentation. Ronald Fenton of Safety Guard was present during the tests and guided the choice of test conditions.

Respectfully submitted, IIT RESEARCH INSTITUTE

Roald Page

Ronald Pape

Manager

Explosion Science Section

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Chemistry and Chemical Engineering

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### 1. BACKGROUND

## Safe-T-Fo11

Safe-T-Foil is a product made by the Safety Guard Corporation. It is designed to eliminate or significantly reduce the potential for explosion of flammable liquids and gases in their storage containers when exposed to hazardous environments such as external fire and ballistic penetration. Safe-T-Foil is essentially a low density metal mesh filling the volume of the storage vessel being protected.

# Hazard Scenarios

There are three hazard scenarios of concern with respect to the potential for explosion of marine gasoline cans. These are (1) sustained external fire-exposure of a can filled with a gaseous fuel-air mixture, (2) ballistic penetration of a can filled with an explosive fuel-air mixture, and (3) a BLEVE (Boiling Liquid Expanding Vapor Explosion) of a tank containing a significant amount of liquid gasoline placed in a sustained external fire.

Calculations were performed to estimate the explosive loading produced within the gasoline cans if a stoichiometric gasoline vapor-air mixture should react within the cans. The calculations were based on octane to represent a typical gasoline mixture. If a classical detonation wave develops within a gasoline can, the peak static pressure would be about 275 psia. This would be the peak pressure on a pressure wave travelling across the can volume at about 2000 m/s. After several wave reflections (or after a constant volume reaction of the mixture inside the can) the pressure will equilibrate to about 130 psig. These marine gasoline cans have been static pressure tested and show significant damage at about 30 psig. Therefore, if an explosive reaction occurs within these marine gasoline cans, significant damage would be expected to occur.

Safe-T-Foil should improve the safety for all three hazard scenarios mentioned above. For a sustained fire exposure of an explosive vapor filled tank, Safe-T-Foil should significantly increase the time before an initiation will occur. Safe-T-Foil should prevent reaction propagation inside a gasoline can whether initiated by sustained fire exposure or by ballistic penetration. For a BLEVE, Safe-T-Foil should serve to lengthen the time before the liquid inside the tank heats up, vaporizes and builds pressure to the point where the can explodes dues to high internal pressure and thermal weakening of the tank wall.

## Current Program

The current program is concerned with the application of Safe-T-Foil to marine gasoline cans. For the current series of tests, the two scenarios involving explosive fuel-air mixtures inside the tanks were evaluated. The BLEVE scenario was not considered. The effectiveness of Safe-T-Foil material was tested for an external pool fire exposure as well as for ballistic penetration with an incendiary round. In both cases, the Safe-T-Foil showed a significant reduction in the potential for explosion of the gasoline cans that were tested.

#### 2. PRINCIPAL OF PERFORMANCE

An expanded metal matrix inside of a gasoline can reduces the explosion nazard in several ways. First, for an external fire exposure, the metal matrix significantly increases the effective heat capacity of the internal gasoline can volume. The implication of increasing the heat capacity is to significantly increase the energy required to heat the spaces inside the can to the point of ignition of any reactive fuel-air mixture within the vessel. The energy input required to heat the spaces inside a can increases by the ratio [MC]<sub>metal-vapor</sub>/[MC]<sub>vapor</sub> when the metal matrix is added to these cans, where MC is the effective heat capacity (mass times specific heat) of the materials. For the cans tested, this factor is estimated to be approximately 20 to 30. In other words, with Safe-T-Foil, it should take about 20 to 30 times more energy input to heat to the explosion temperature.

The actual process of heating the gasoline cans is an extremely complex heat tranfer problem. In reality, the thermal ignition process occurs at or near the wall of the gasoline can because this is the hottest surface. For gasoline cans without Safe-T-Foil, an internal convective flow will develop and help to remove heat from the hot walls of the can. For cans containing Safe-T-Foil, contact of the foil with the wall will help to cool the wall by conduction heat transfer. For any heating process controlled by conduction, the rate of heating is characterized by the molecular diffusivity of heat a,

$$\alpha = \frac{k}{oC}$$

where k is the conductivity,  $\rho$  is the mass density, and C is the specific heat. The term  $\rho$ C is equivalent to the heat capacity MC mentioned earlier. Thus, when considering rate of heating, a high heat capacity can be negated if the conductivity is also high, as in the case of the metal matrix in a gasoline can. Although it takes more energy to achieve a critical (ignition) temperature level, the energy flows into the matrix more easily. Therefore,

the metal matrix may or may not inhibit the temperature rise inside the can due to external heating, depending on whether heat capacity or conduction dominates.

A primary benefit of Safe-T-Foil is that it will inhibit the propagation of an energetic reaction (deflagration or detonation) within the gasoline can if ignition does occur, either by external heating or by incendiary ballistic penetration. This flame propagation inhibitor property of Safe-T-Foil is illustrated by a simple model. A single idealized channel within an Safe-T-Foil matrix is shown in Figure 1 with a flame propagating through the channel. If the flame is viewed as a constant thickness (a) uniform temperature chemical reaction zone moving at constant propagation velocity  $V_{\rm f}$ , than an energy balance on the moving slab leads to the following estimate for the flame temperature  $(T_{\rm f})$  history.

$$T_{f} - T_{o} = \frac{\rho_{g}V_{f}H_{f}D}{4h\Delta} \left\{1 - \exp\left(-\frac{4h}{\rho_{g}C_{g}D}t\right)\right\} + \left(T_{f} - T_{o}\right) \exp\left(-\frac{4h}{\rho_{g}C_{g}D}t\right)$$

Energy Addition

Energy Extraction

where  $\rho_g$  is the gas density, D is the channel diameter,  $C_g$  is the gas specific heat,  $H_f$  is the reaction enthalphy, h is the convective heat transfer coefficient,  $T_0$  is the initial temperature of the metal mesh and flammable gas mixture and  $T_f$  is the initial flame temperature. The first term on the right represents energy addition by reaction and the second term represents energy loss by heat transfer to the cell wall. Both terms have the same time constant in this model:

Since flame suppression is desirable in as short a time as possible it is desirable for the time constant to be as short as possible (i.e., small diameter channels, D, but not so small as to inhibit convective heat transfer, h), and it is desirable to have the energy extraction term dominate over energy addition (i.e., small channel diameters, again).

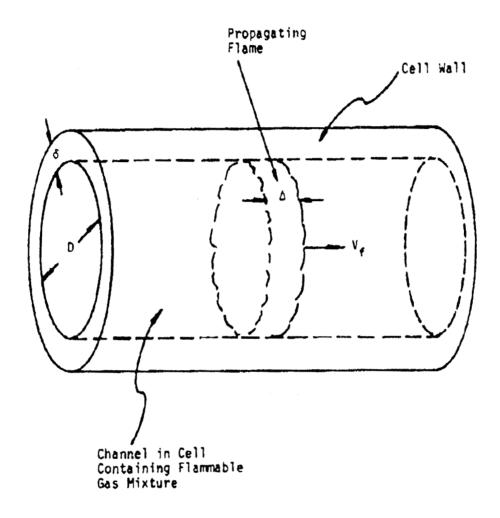


Figure 1. Idealized model for single channel for flame propagation within Safe-T-Foil matrix.

It should also be beneficial to maximize the ratio of energy absorbed by the cell wall to energy released in the cell volume:

Energy Absorbed Energy Released 
$$\frac{4p_5\delta C_S(T_S - T_O)}{p_0D H_f}$$

where  $\rho_S$  is the metal density,  $\delta$  is the cell wall thickness, and  $C_S$  is the metal specific heat. This indicates that the metal cells should maximize the ratio of cell wall thickness to cell diameter, as well as maximize the wall heat capacity ( $\rho_S C_S$ ).

A comprehensive investigation of the Safe-T-Foil concept was conducted by the Canadian Explosafe Division, Vulcan Industrial Packaging, Ltd. for the U.S. Air Force\* for aircraft fuel tank protection. That study determined a 2 mil foil thickness and a packing density of approximately 2  $lb/ft^3$  to be optimum. These specifications were chosen for the Safe-T-Foil used in the marine gasoline cans tested in this program.

<sup>\*</sup>A. Szego, et al," Evaluation of Explosafe Explosion Suppression System for Aircraft Fuel Tank Protection", AFWAL-TR-80-2043, July 1980.

#### 3. TEST PROGRAM

Two series of tests have been performed at IIT Research Institute's Gary Indiana Fire Laboratory. The first series of tests was to verify that Safe-I-foil reduces the explosion hazard of marine gasoline cans filled with an explosive gasoline vapor-air mixture when penetrated by a ballistic incendiary round. The second series of tests was to verify that Safe-T-Foil reduces the explosion hazard of these same gasoline cans exposed to an external sustained fire.

#### 3.1 BALLISTIC INCENDIARY PENETRATION TESTS

# Test Setup

The physical arrangement for the ballistic penetration tests is shown in Figure 2. These tests were simply shooting an 50 caliber incendiary round into each can through a 1/4 inch thick aluminum plate to cause ignition of the incendiary prior to penetration into the gasoline can. The gasoline cans were filled with a flammable mixture of gasoline vapor and air, 5 ml of gasoline for the majority of the trials.

### Diagnostics

The diagnostics for these tests was simply video camera coverage. Explosion of the gasoline cans was clearly identifiable from the video record.

#### Test Sequence

The initial trials were to establish a baseline condition with unprotected cans. This was essentially to verify that the unexploded cans do indeed explode when penetrated by an incendiary round. Once the baseline was established, the protected cans were tested to verify that Safe-T-Foil does indeed prevent explosion by this type of ignition source.

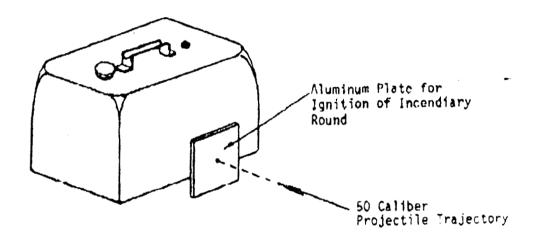


Figure 2. Ballistic penetration test setup.

### 3.2 POOL FIRE TESTS

## Test Setup

The physical arrangement for the pool fire exposure tests is shown in Figure 3. Each six gallon marine gasoline can was placed in a shallow pool of liquid gasoline, representing an accidental spill. The cans were each filled with 5 ml of gasoline, which when vaporized produced a flammable fuel-air mixture within the can. These tests were each begun by initiation of the gasoline in the shallow pan using an electric squib to ignite a bundle of matches positioned just above the surface of the gasoline in the pan.

### Diagnostics

The diagnostics for these experiments consisted of real time video coverage, five thermocouples, and pressure history inside the can. The five thermocouples were located as described below:

- 1 thermocouple inside the can, halfway up from the bottom, penetrating through the threaded connection provided in the top of the can.
- 2 thermocouples tack welded to the outer wall of the can, at 1/3 and 2/3 of the can height from the bottom.
- 2 thermocouples in the pool fire flame 1" from the can wall, at 1/3 and 2/3 of the can height from the bottom.

#### Test Sequence

An initial series of pool fire tests were conducted with gasoline cans that did not contain Safe-T-Foil. The purpose of the initial tests was to establish a baseline condition under which the unprotected cans will explode. Based on the initial series, the protected gasoline cans were each exposed to the same type of fire for an extended time.

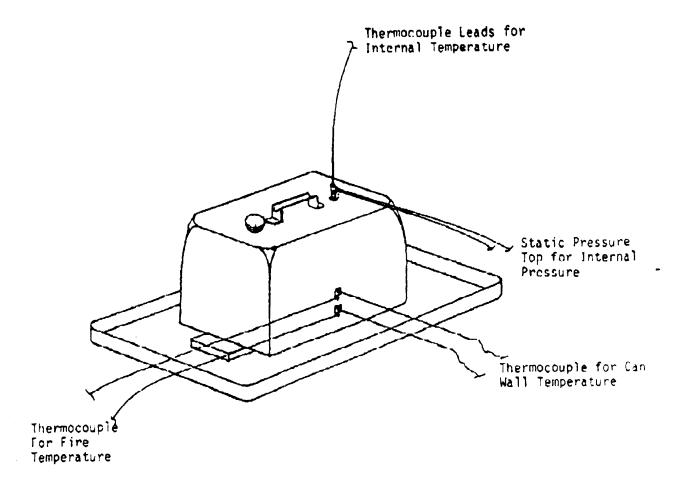


Figure 3. Pool fire test setup.

### 4. TEST RESULTS

The tests which were performed and the test results are summarized in Table 1. Table 1 also shows a verification of foil weight inside two protected cans chosen at random. The measured weights were within 0.6 percent of the specified weights.

#### 4.1 BALLISTIC TESTS

Seven ballistic penetration tests were performed. These tests were uninstrumented. Evaluation of these tests results were based on visual observations, post test gasoline can damage, and the video coverage.

The first two tests were on unprotected gasoline cans, filled with 5 ml of gasoline in each case. In both cases the cans exploded, with the primary failure at the seam beteeen the can bottom and the main body of the can. All the other tests involved protected cans. None of the protected cans exploded. After each test, these cans remained in their original position, with the only perceptable damage being a bullet hole and blackl scorch mark surrounding the bullet hole. In Test 7 (1 liter of gasoline in can), a delayed flash of light was observed, but the gasoline can did not sustain any additional damage.

## 4.2 POOL FIRE TESTS

Six pool fire tests were performed. Tests 8 and 13 were baseline trials using unprotected gasoline cans. In Test 8, the can exploded after 68 seconds. In Test 13, the fill cap was blown off (prematurely) at 51 seconds resulting in the can being knocked off of its stand in the pan. All of the pool fire tests with protected cans involved a flammable vapor-air mixture in the can (5 ml of gasoline). No explosions were observed in any of these tests. All of these gasoline cans vented to the atmosphere after several minutes when the fill cap gasket failed. This expelled the flammable fuel-air mixture from the can, climinating the hazard.

TABLE 1. SUMMARY OF TESTS PERFORMED

Test No.	Test Type	Protection	Fo11 Weight	Gasoline in Can	Results
1	Ballistic	Unprotected (baseline)	0 g	5 m]	Explosion
2	Ballistic	Unprotected (baseline)	<b>0</b> g	5 ml	Explosion
<b>3</b> .	Ballistic	Protected	1000 g	5 m l	No explosion
4	Ballistic	Protected	1000 g	5 m7	No explosion
5	Ballistic	Protected	819 g	5 m7	No explasion
6	Ballistic	Protected	1055 g	10 m?	No explosion
7	Ballistic	Protected	1020 g	1 1	No explosion, but late time flash occurred
8	Pool Fire	Unprotected (baseline)	0 g	5 m1	Explosion at 68 sec
9	Pool Fire	Protected	871 g	5 ml	No explosion
10	Pool fire	Protected	888 g	5 ml	No explosion
11	Pool Fire	Protected	1000 g	5 ml	No explosion
12	Pool Fire	Protected	10 <b>9</b> 1 g	5 ml	No explosion
13 ·	Pool Fire	Unprotected (baseline)	0 g	5 m1	Fill cap blown off at 51 sec (minor explosion)

# Verification of Foll Weight

Gasoline Can Specification	Indicated Foil Mass	Measured Foil Mass	Error
В	975 gm	972 gm	0.3%
C	1028 gm	1022 gm	0.6%

The thermocouple and pressure transducer readings are presented in Figures 4 through 9 for Tests 8 through 13, respectively. In each case, the top graph presents the external temperatures (the fire temperatures at 2 levels and the gasoline can outer wall temperatures at 2 levels). The middle graph is the temperature history recorded at the mid-height within the can, and the bottom graph is the internal can pressure.

When the temperature and pressure histories from Test 8 (unprotected can which exploded) are comapred to those of the protected cans, the responses of all the cans are seen to be similar. Even internal temperature and pressure were comparable. This indicates that the dominant mechanism for explosion prevention is probably the ability of the metal mesh to prevent reaction propagation, as opposed to increasing the heat capacity of the can. Test 13 (unprotected can for which the fill cap blew off) does show a sharp rise in temperature just before the fill cap blew off the can and relieved the internal pressure.

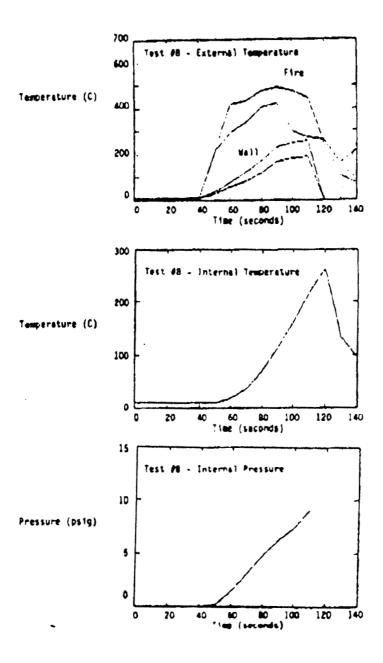


Figure 4. Test 8 results.

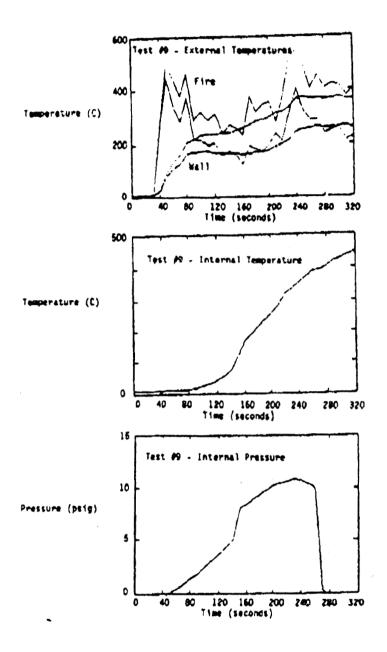


Figure 5. Test 9 results.

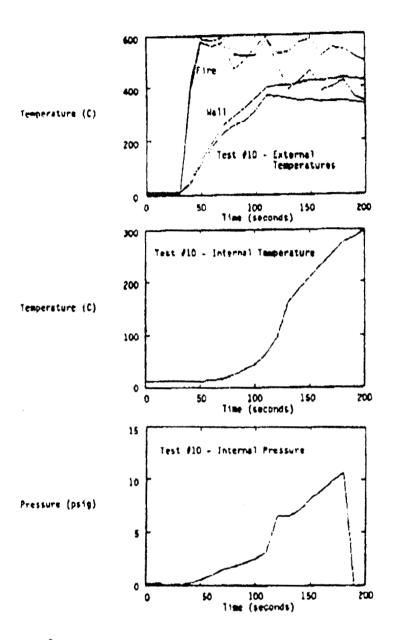


Figure 6. Test 10 results.

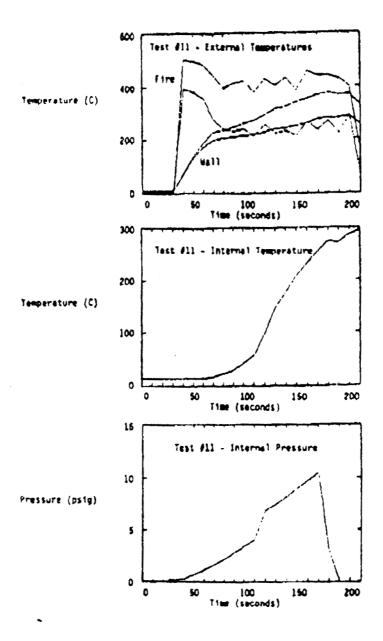


Figure 7. Test 11 results.

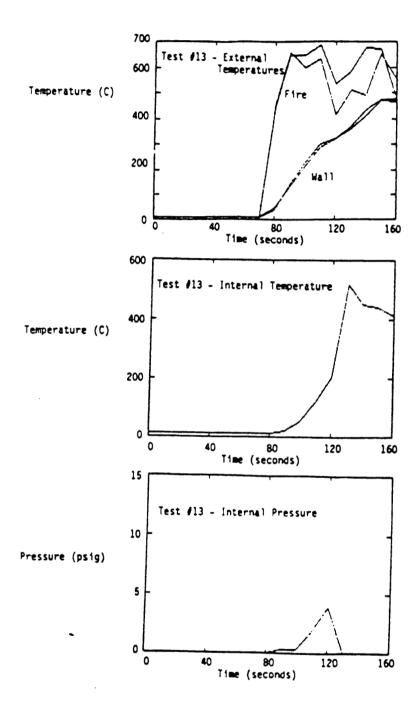


Figure 9. Test 12 results.

## 5. CONCLUSIONS

Based on the experiments performed under this program, the Safe-T-Foil material showed a definite reduction in the potential for explosion of the marine gasoline cans that were tested, when these gasoline cans are exposed to a sustained external fire or penetration by a 50 caliber incendiary projectile. It must be noted that these gasoline cans were tested in most cases containing a flammable mixture of gasoline vapor in air. This should be the worst case for an internal explosion due to chemical reaction. Safe-T-Foil is expected to provide the same type of explosion protection as was demonstrated in this program to any gasoline can of a similar type.

# DRAFT REPORT NOVEMBER 16, 1992

A REVIEW OF PROPANE TANK TEST DATA CONDUCTED BY PACKER ENGINEERING, INC. NAPERVILLE, IL

FOR

SAFETYTECH CORP. MT. PROSPECT, IL.

BY

WALLACE SHAKUN, PHD 420 JEFFERSON CIRCLE ATLANTA, GA 30328

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B-PACKER ENGINEERING DATA COLLECTION

#### ABSTRACT

An analysis was conducted of the data collected by Packer Engineering, Inc. for each of the supplied propane test tanks. Appendix A is a series of tables developed in order to analyze the test data. Appendix B is the basic data and associated graphs presenting the tank pressure (regulator upstream) as a function of the elapsed time as presented by Packer Engineering, Inc.

#### CONCLUSION

- 1) LPG tanks with foil inserts perform differently when compared to LPG tanks with-out foil
- 2) The overall weight of the tank (no liquid) does not appear as a major factor in the operational characteristics of the tanks tested
- 3) The primary difference in the characteristics of the tanks with foil appears to be related to the foil density (weight of aluminum material-ounces to the tank capacity-gallons)
- 4) The tanks with the foil material inserts exhibited a higher vapor pressure than the tanks with-out the foil material for the same elapsed test time. The issue to be resolved is: Did all test have the same initial conditions when t=0? In order to correct for different initial conditions the data has been normalized as appropriate. Table 3 and Table 6 present normalized test data based on two different mathematical procedures. It appears that the tanks with the foil inserts have the potential to exhibit a higher relative vapor pressure then the tanks with-out the foil. The results indicate that the higher vapor pressure is probably the result of as higher heat transfer rate into the propane liquid resulting from the foil inserts within the LPG cylinders.

#### TEST DATA ANALYSIS

Table 1 is the basic upstream vapor pressure for each tank tested as a function of elapsed time. The tanks are identified as:

TANK #	FOIL DENSITY (OZ/GAL)
1	4.10
2	4.71
3	5.53
4	6.32
7	6.32 (different band width)
5	no foil
6	no foil
(5+6)/2	no foil-average value

Table 2 is the basic upstream vapor pressure differences for each tank tested as compared to the average upstream vapor pressure for the tanks with no foil inserts. The basic data indicates that the tanks with the different foil densities have a higher tank vapor pressure difference than the tanks with-out the foil. The higher vapor pressure within the tanks with the foil inserts appears to be indicative of a higher heat transfer rate into the tanks from the surrounding conditions. The vapor pressure differences decrease as a function of the elapsed time and will probably approach a steady state final differential vapor pressure. The vapor pressure difference ratio at t=1 minute divided by the vapor pressure differences at t=31 minutes for each tank tested is:

TANK #	RATIO: <u>DELT P (t=1 minute)</u> DELT P (t=31 minutes)
	·
1	5.10
2	3.10
3	3.80
4	3.10
7	2.70 (different band width)

From the above data it appears that the tanks with the higher foil density have a lower vapor pressure difference ratio indicative of a higher heat transfer rate from the ambient into the LPG liquid.

Table 3 is the vapor pressure ratio defined as: the vapor pressure at t=1 minutes to the vapor pressure at t=1 minute. In general, the overall vapor pressure ratio of the tanks with the foil inserts appear to have the characteristics of a higher vapor pressure ratio as the elapsed time increases as compared to the tanks with-out foil. The vapor pressure ratio coefficient is defined as the vapor pressure ratio at t=1 minute divided by the vapor pressure ratio at t=31 minutes for each of the tanks tested are:

TANK #	PRESSURE RATIO COEFFICIENTS
1	3.36
2	3.24
3	3.39
4	3.20
7	3.20 (different band width)
(5+6)/2	3.43
<b>`</b> 5	3.56

The lower value of the vapor pressure ratio coefficient for the tanks with the foil inserts is indicative of a lower vapor pressure ratio coefficient slope, hence a higher heat transfer rate for the tanks with the foil inserts as compared to the tanks without the foil material.

Table 4 is defined as the pressure ratio at time t=i minutes divided by the average vapor pressure for the two tanks tested with-out the foil inserts. Comparing the vapor pressure ratios indicate that the tanks with the foil inserts have a higher vapor pressure ratios as compared to the tanks with-out the foil inserts. The vapor pressure ratio coefficients is defined as the vapor pressure ratio at t=1 minute divided by the pressure ratio at t=31 minutes are:

TANK #	PRESSURE RATIO COEFFICIENTS
1	1.04
2	.98
3	1.02
4	.96
7	.94 (different band width)

The lower value of the vapor pressure ratio coefficients for the tanks with the higher density foil inserts appears to indicate a higher vapor pressure ratio as a function of the elapsed test time. Table 5 is defined at the vapor pressure difference for a tank at time =i minutes minus the vapor pressure at time = (i+2) minutes for a starting vapor pressure of approximately 79 psi. The data appears to indicate that the tanks with foil inserts have a greater vapor pressure difference than tanks with-out the foil (with the assumption that all tanks have the same initial vapor pressure, 79 psi). Since the downstream vapor pressure is regulated for the test conditions therefore the difference in pressure from t=29 minutes to t=31 minutes under the test conditions are:

TANK #	PRESSURE DIFFERENCES (t=29-t=31)
1	2.5
2	3.5
3	3.5
4	3.5
7	4.0 (different band width)
(5+6)/2	3.0

If all the test tanks have the same final regulated steady state vapor pressure than the initial vapor pressure for the tanks with the foil insert is expected to be higher than the tanks without the foil.

Table 6 is defined as the initial vapor pressure at t=1 minute minus the vapor pressure at t=i minutes. The test data indicates that the tanks with the foil has a greater vapor pressure difference than the tanks with-out the foil insert. If we assume that all the test tanks have the same final regulated steady state vapor pressure of 28 psi than the expected initial pressures (based on a linear function) are:

TANK #	PRESSURE DELTA (t=1-t=31)	VAPOR PRESSURE INITIAL t=0
1	64.5	92.5 psi
2	66.0	94.0
3	70.5	98.5
4	76.5	104.5
7	73.0	101.0 (different band width)
(5+6)/2	56.5	84.5

APPENDIX-A DATA ANALYSIS TABLE 1 TO 6 INCLUSIVE

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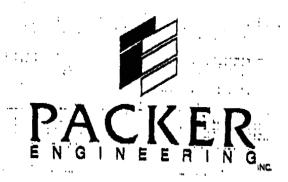
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**YIA FACSIMILE** 

November 4, 1992

Mr. Ron Fenton
SAFETYTECH CORPORATION
1749 Gulf Road
Suite 500
Mt. Prospect, IL 60056

Re: Propane Tank Testing

Packer Engineering File No.: N51163

Dear Mr. Fenton:

Enclosed is a draft of the appendix summarizing the measured data points for each of the supplied propane tanks. Also, enclosed are seven graphs presenting the tank pressure (regulator upstream) versus time.

If you have further questions regarding the presented results, please do not hesitate to call me.

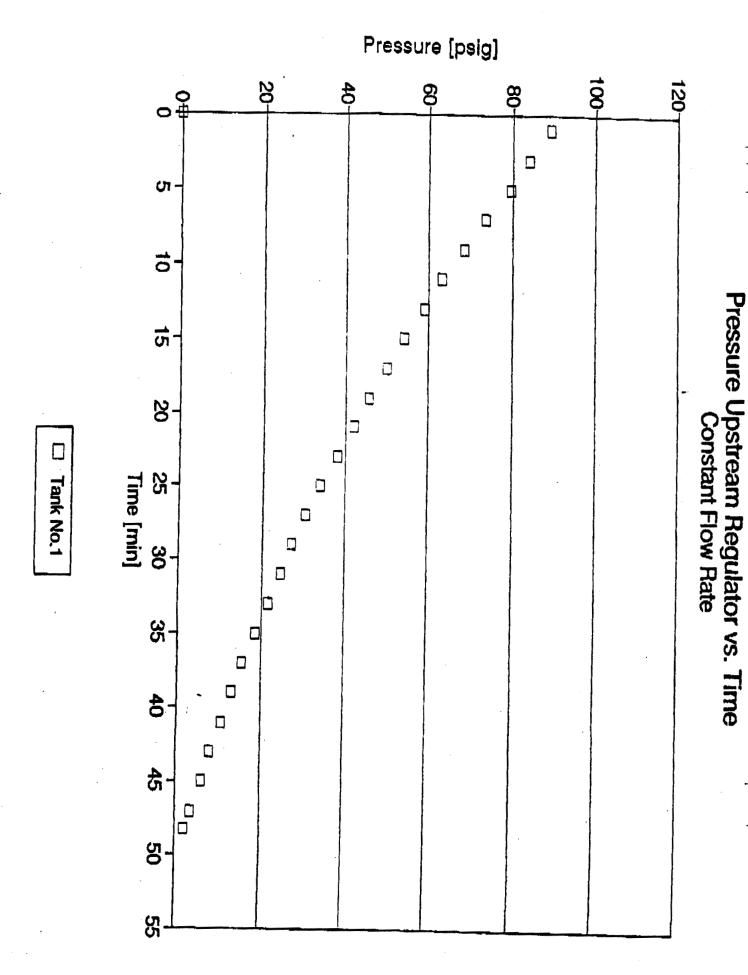
Sincerely,

Christoph Graumann

Staff Engineer

(Intern Program)

Client	: Saeflytech Co	Saeftytech Corporation, Mr. Ron Fertion	Fenton					Page:1	7: <b>J</b> o
File No. By	: N51163 : Christoph Graumann	umann	Title Date	: Propane Tank Test : 22/10/1992					85
Tarnk No. 1		: FB 000100	Tank weight initi	nt inklially (empty)	: <del>1</del>	Average Mass Flow	<b>M</b> .	: 0.15781 lb/mln	
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5.00	79.50	7.40	8.00	0.47	0.57	0.47	59.84	55.42	55.58
7.00	73.50	7.40	8.00	0.45	0.57	0.41	59.64	52.43	54.58
006	68.50	7.60	8.00	0.46	0.56	0,33	59.35	48.44	55.08
11.00	63.00	7.70	8.00	0.46	95.0	0.26	58.86	44.96	55.08
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27.00			8.10	0.53	0.47	-0.31	54.96		58.59
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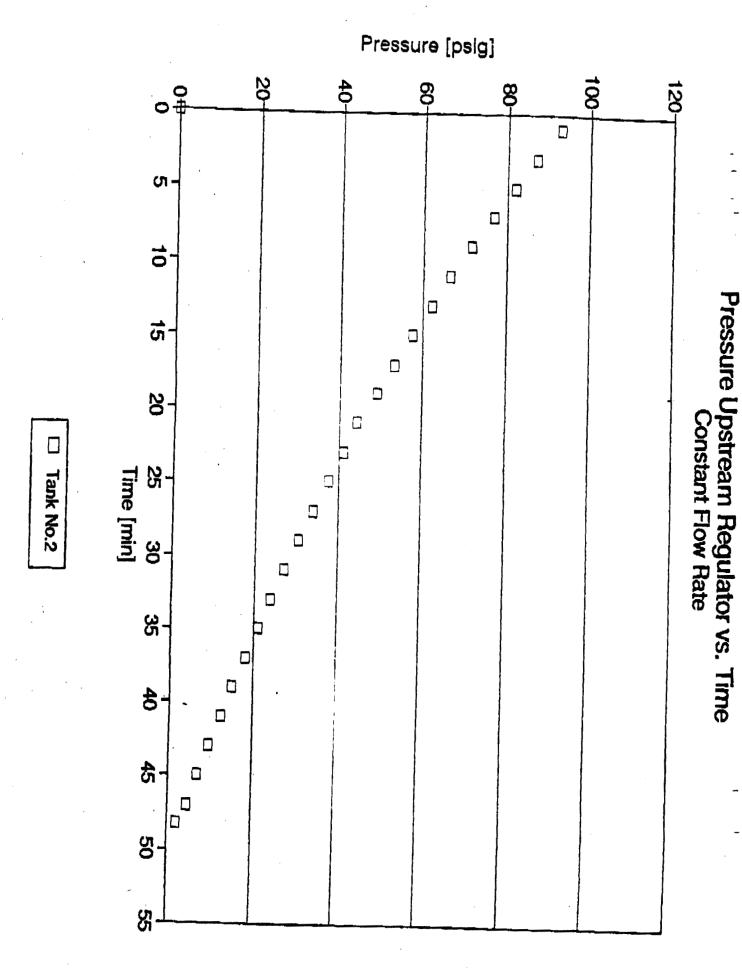


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December	7: 20	: 0.15816 lb/min : 772 mm Hg : 65,5 F		Temp. Tank Up Temp. Lank Low Temp. Stream		64.89	61. <del>1</del> 0	26.95	53.43	50.44	46.95	43.46	39.47	35.99	32.00	28.01	24.03	21.04	17.05	12.07	90.6	5.59	0.61	3.38	-6.87	-10.36	-12.35	-15.84	-17.33	-19.82	-1833	
		Flow Ire Iratura		_	Ŧ	63.75	62.28	60.83	S9.35	57.89	56.91	25.44	54.47	53.00	52.02	51.05	49.58	48.61	47.63	46.65	45.68	44.78	44.21	43.23	42.75	41.77	60.79	40.30	39.81	38.84	37.86	.*
		Average Mans Flow Ambient Pressure Ambient Temperatur		Tomps, Lank U Temps, Tank Low	lmV.	99.0	A S	UCU C	0.43	0.37	0.30	0.63	0.15	0.08	00.00	80.0	-0.16	422	0.30	-0.40	-0.46	D.53	ଦ୍ୱ	-0.71	97.0	-0.85	080	96.0	66.0	20,7	-1.01	
	# Test	: 44.25 lb : 61.25 lb : 204.89	•	Temp, Iank U	Au	0.00				200	0.01	97.0	0.40	25.0	0.41	0.39	0.30	45.0	0.32	0.30	82.5	0.26	0.25	0.23	0.22	0.20	0.18	0.17	0.16	0.14	0.12	
	: Propane Tank Test : 22/10/1992	Heiby (empty)	Town Cd.	Im V	32.0	0.56	0.51	0.49	0.49	0.40	0.50	0.50	0.50	A. C.	0.50	0.0	0.30	0.57	BC:0	90.0	300	0.01	0.01	0.00	0.03	0.04	0.0	500	0.00	8.0	00.0	T
Fenton	Title Date	Tank weight initially (empty) Test weight Average BTU/hr.	do Orifice Plata		000	8.00	8.10	8.10	8.00	8.10	8.00	8.00	8 00	28	8.00	008	808	000	3.0	300	200	00.0	000	0.00	0.00	2 0	2 4	0 4	0 0	7.80		T
Saetytech Corporation, Mr. Ron Fenton	mann	: FB 000097 : 17 lb : 7.75 lb	p upstr. Regul. p downstr. Beaul.	In* H2O	000	7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.80	7.80	7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.80	7.80	7.85	7.85	28.7	7.80	7.80	087	7.80		
	: NST 163 : Christoph Graumann	<b>z</b> _	p upstr. Regul.	[isd]	00'0	00.58	87.00	82.00	77.00	71,50	06.50	00.29	57.50	53.00	49.00	44.00	41.00	37.50	38.00	30.50	27.00	24.00	21.00	18.00	15.00	12.50	9.50	7.00	4.50	200		
Ello Mo	By	Taink No. 2 Propane weight Propens used	Three	[min]	00'0	1.00	3.00	2.00	7.00	9.00	11.00	13.00	15.00	17.00	19.00	21.00	23.00	25.00	27.00	29.00	31.00	33.00	35.00	37.00	39.00	41.00	43.00	45.00	47.00	49.00		

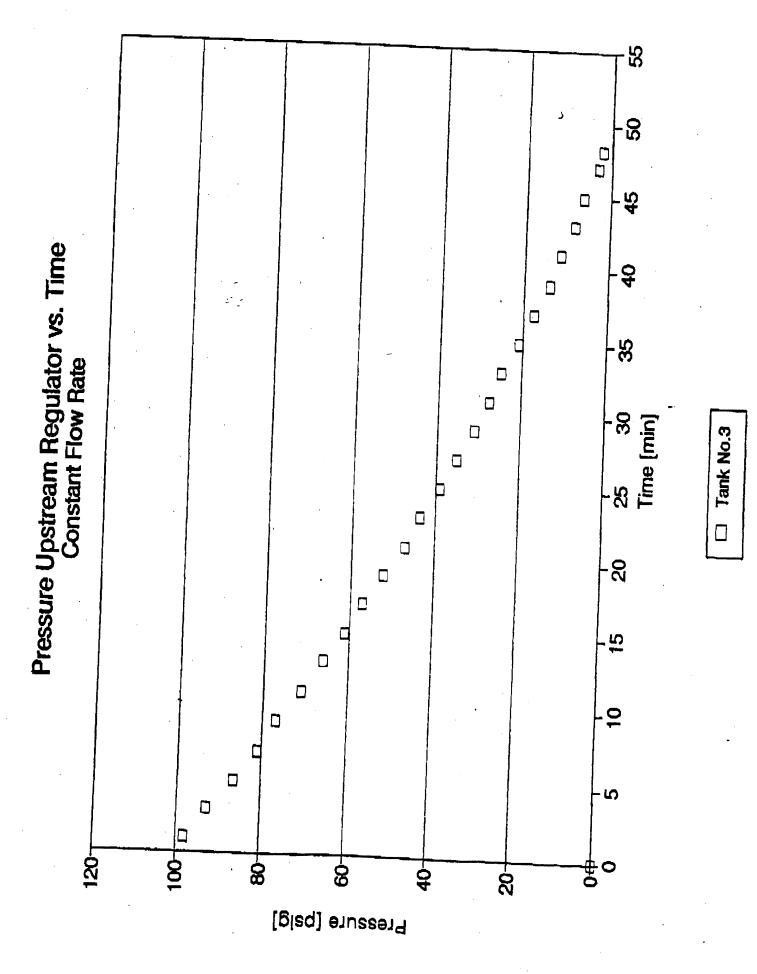
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THU, MAY TENDONOTION

INSTE BUTTIMME



No. 3   : FB 000062   Tank week   : 17 lb   Test   Test	initially (empty)	: 445 lb : 61.5 lb : 198.35 : 198.35   Graph Tank U   Graph Tank U	### Average Mass Flow   61.5 lb		: 0.1531 : 772 mar : 66 F : Temp.Tar	Iomp. Stroam
P. upodr. Regul   p douvnedr. Regul   dp Orffice	Lyte.  Lete Temp.Streener  [mV]  00 0.73  10 0.52  10 0.47  00 0.45  00 0.43	: 198.35 : 198.35 ImM) 0.78 0.77 0.72 0.72 0.72 0.72	Amblent Press Amblent Tempa Temp. Temp. Temp  O.74  O.59  O.58  O.59  O.44		: 0.153114 lb/m : 772 mm Hg : 66 F P Temp. Tank Low	Tomp. Stream
0.00         P uppelf. Regul         p downself. Regul         dp Outline           0.00         0.00         0.00         0.00           1.00         98.00         7.80         7.80           5.00         86.50         7.80         7.80           7.00         86.50         7.80         7.80           17.00         71.00         7.60         8           17.00         71.00         7.60         8           15.00         61.00         7.60         8           15.00         61.00         7.60         8           15.00         61.00         7.60         8           23.00         7.60         7.60         8           23.00         7.60         7.60         8           25.00         33.00         7.80         8           25.00         35.00         7.80         8           25.00         27.50         7.80         8           25.00         27.50         7.80         8           25.00         27.50         7.80         8           25.00         27.50         7.80         8           27.00         7.80         8	Temp.Stream   0.73   0.52   0.43   0.43	(mV) 0.78 0.77 0.72 0.72 0.70 0.70 0.70 0.70 0.70	Temp. Territ Low [mV] 0.74 0.72 0.67 0.67 0.58		: 66 F  Temp. Tenk Low	Temp. Stream
0.00         0.00         0.00         0.00           3.00         98.00         7.80           5.00         86.50         7.80           5.00         86.50         7.80           7.00         86.50         7.80           7.00         81.00         7.80           17.00         77.00         7.80           13.00         66.00         7.60           17.00         7.60         7.60           17.00         7.60         8           23.00         43.50         7.60           25.00         39.00         7.60           25.00         35.00         7.80           25.00         27.50         8           33.00         7.80         8           35.00         7.80           35.00         7.80           35.00         7.80           35.00         7.80           35.00         7.80           35.00         7.80           35.00         7.80           35.00         8.6           35.00         7.80           35.00         8.6           35.00         8.6           35.00	Famp.Stream [mV] 0.73 0.52 0.47 0.45	Inty Tank U  Inty  0.78  0.74  0.72  0.72  0.70  0.70  0.70  0.69	Temp. Territ Low [mV] 0.74 0.72 0.67 0.58 0.58		P Temp. Tank Low	Temp. Stream
00 0.00 0.00 0.00 0.00 0.00 0.00 0.00	0.73 0.73 0.47 0.43	0.73 0.74 0.72 0.72 0.70 0.69 0.69	(mV) 0.74 0.72 0.67 0.58 0.58 0.54		Temp. Tank Low	Temp. Stream
00 98.00 7.80  00 66.50 7.80  00 66.50 7.80  00 66.00 7.80  00 66.00 7.80  01 61.00 7.80  025.00 7.80  039.00 7.80  035.00 7.80	0.73 0.47 0.43	0.78 0.72 0.72 0.70 0.69 0.69				(F)
00 98.00 7.80 7.80 7.80 7.80 7.80 7.80 7.80		0.77 0.77 0.72 0.00 0.69 0.69	0.67 0.67 0.58 0.59 0.44			1
00		0.74 0.70 0.70 0.69 0.69	0.67			<b>68.6</b> 2
00 81.00 7.80 7.80 7.80 7.80 7.80 7.80 7.80 7		0.72	0.58		67.88	50.85
77.00 7.80 7.80 7.80 7.80 7.80 7.80 7.80		0.70	0.50		65.39	55.58
71.00 7.80 (66.00 7.60 7.60 (7.80 66.00 7.60 7.60 7.60 7.60 7.60 7.60 7.		0.70	0.44		06'09	\$4.58
66.00 7.60 7.60 7.60 7.60 7.60 7.60 7.60	0.43	0.69	**			53.57
61.00 7.60  57.00 7.60  43.50 7.60  43.50 7.60  39.00 7.60  35.00 7.80  8 35.00 7.80  8 27.50 7.80  8 27.50 7.80  8 17.50 7.80  8 17.50 7.80  8 17.50 7.80  8 17.50 7.80	7.90 0.43	0.66	36.0	66.19		53.57
7.60 7.60 7.60 7.60 7.60 7.60 7.60 7.60 7.60 7.60 7.80 8 7.80 8 7.80 8 7.80 8 7.80 8 7.80 8 7.80 8 7.80 8 7.80 8 7.80 8 7.80 8 7.80 8 7.80 8 7.80 8 7.80 8 7.80 8 7.80 8 7.80 8 8 7.80 8 8 7.80 8 8 8 7.80 8 8 8 8 7.80 8 8 8 8 7.80 8 8 8 8 8 8 8 8 8 8 8 8 8	7.90 0.44		30.0	8.0	49.44	53.57
25.00 7.60 7.60 7.60 7.60 7.60 7.60 7.60 7	7.90 0.45	30.0	0.40	X. 3	44.96	54.07
38.00     7.80       38.00     7.80       31.00     7.80       27.50     7.80       27.50     7.80       21.00     7.80       17.50     7.80       14.00     7.80       11.50     7.80	7.90 0.46	190	0.13	92.33	41.47	57.58
38.00 7.80 7.80 27.50 27.50 27.50 27.50 27.50 27.50 27.50 27.50 27.50 27.50 27.50 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8	90 0.47	0.59	000	61.79	35,99	55.08
35.00 7.80 35.00 7.80 27.50 7.80 27.50 7.80 21.00 7.80 17.50 7.80 8 7.80	8.00 0.48	0.57	200	28.09	33.99	55.58
35.00     7.80     8       31.00     7.80     8       27.50     7.80     8       25.00     7.80     8       21.00     7.80     8       17.50     7.80     8       14.00     7.80     8       11.50     7.80     8	00 0.49	0.55	10.0	28.85	31.50	56.08
31.00     7.80     8       27.50     7.80     8       25.00     7.80     8       21.00     7.80     8       17.50     7.80     8       14.00     7.80     8       11.50     7.80     8	0.50	0.53	9.5	58.86	29.51	56.58
27.50 7.80 25.00 7.80 21.00 7.80 14.00 7.80	00 0.51	0.51		57.89	26.52	57.09
25.00 7.80 21.00 7.80 17.50 7.80 14.00 7.80	8.00 0.53	0.49	4.17	26.91	23.53	57.59
21.00 7.80 17.50 7.80 14.00 7.80		0.47	770	55.93	21.04	58.59
17.50 7.80 14.00 7.80		0.45	0770	24.96	18.05	58,59
14.00 7.80		0.43	200	88.38	15.56	59.03
11.50	0.55	0.41	4.37	23.00	13.56	59.59
06.11	95.0	0.40	24.0	25.02	11.07	59.59
7.00	0.56	0000	-0.46	51.54	90'6	60 10
8 07.7 8.8	10 0.57	0.00	0.50	50.56	7.08	60 10
OC D		0.95	-0.54	50.07	5.09	60.60
300		3 6	85.0	49.09	3.10	90.60
		0.25	6.54	48.12	0.11	60.60
			9.00	48.12	0.69	60.60



Christoph Graumann	Christoph Craumann Date	Tide Date	: Propane Tank Tests : 22/10/1992	ok Tests			Page : 4	1:10
	: FB 000069 : 17.25 lb : 7.75 lb	Tank weight initia Test weight Average BTU/hr.	ially (empty)	: 45.25 lb : 62.5 lb	Average Mass Flow Ambient Pressure		: 0.151122 lb/min : 772 mm Ho	£
P upstr. Reced				1.00.	Ambient Temperatur	raturo	. 66 F	
	fire H201	op Orffice Plate	Temp.Stream	Temp. Tank U	Tome Text 1			
0.00	0.00		[mV]	[mV]	[mV] [mV] ImV	emp. Tank Up	Temp.Tank Low	Temp. Stream
108.50	7.80	000	0.63	0.81	57.0		[F]	(F)
101.00	7.80	0.00	0.43	0.78	250	90"17	69.37	63.61
94.00	7.7	07.9	0.39	0.76	0.54	01.0/	65.89	53.57
88.00	02.7	867	0.37	0.74	10.0	69.12	62.40	5157
8200	7.00	7.90	0.35	0.71	P. C.	68.14	58.91	50.56
75 CD	1.00	7.90	0.35	8870	0.47	66.68	55.42	40 CE
8 2	Ω/	7.90	0.35	90	0.30	65.21	51.43	49 55
25.55	97.7	7.90	0.36	800	25.0	63.73	47.95	40.56
3 8	7.70	7.90	0.37	200	0.25	62.28	44.46	00.01
3 8	7.70	7.90	820	B. S.	0.17	60.82	40.47	20.00
3 8	7.70	7.90	0.00	0.30	0.10	59.35	36.00	30.36
808	7.80	7.65	3 3	0.53	0.04	57 80	00.00	51.06
47.50	7.60	82	0.41	0.50	<b>90.0</b>	3.5	23.50	51.57
43.50	7.60	200	0.42	0.47	0.10	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	30.51	52.57
39.50	7.60	2.00	0.43	0.45	0.17	8.5	27.02	53.07
35.50	7 80	3.	0.44	0.43	200	De la	23.53	53.57
32.00	7 200	8:00	0.46	0.41	700	23.00	21.54	54.07
28.00	26.7	9.00	0.47	0.39	300	2202	19.54	\$5.08
25.50	2.00	800	0.48	0.37	0.00	51.05	17.55	55.58
2 2	30.7	8.00	0.49	0.35	0.33	20.02	15.56	SS 08
10.00	7.00	8.00	0.50	0.33	10.37	49.09	13.56	56.58
200	89.	8.00	0.51	2	-0.43	48.12	11.57	57.00
3 8	7.80	8.00	0.00	0.00	4.0	47.63	10.07	8 6
3.00	7.80	8.00	500	180	0.49	47.14	7.58	B
10.00	7.60	8.8	700	0.23	-0.53	46.16	3 2	3
7.50	7.80	90.0	0.53	0.28	0.57	AF 28	3.58	58.09
5.00	7 80	3.5	0.54	0.26	S	87.7	3.60	58.50
250	7 80	00.0	0.54	0.25	200	6.45 4.70	2.10	50.03
	POC.	7.60	0.55	0.23	500	44.21	0.11	89.09
					3	3		7

Client File No. By 0.00

Imin (

3.00

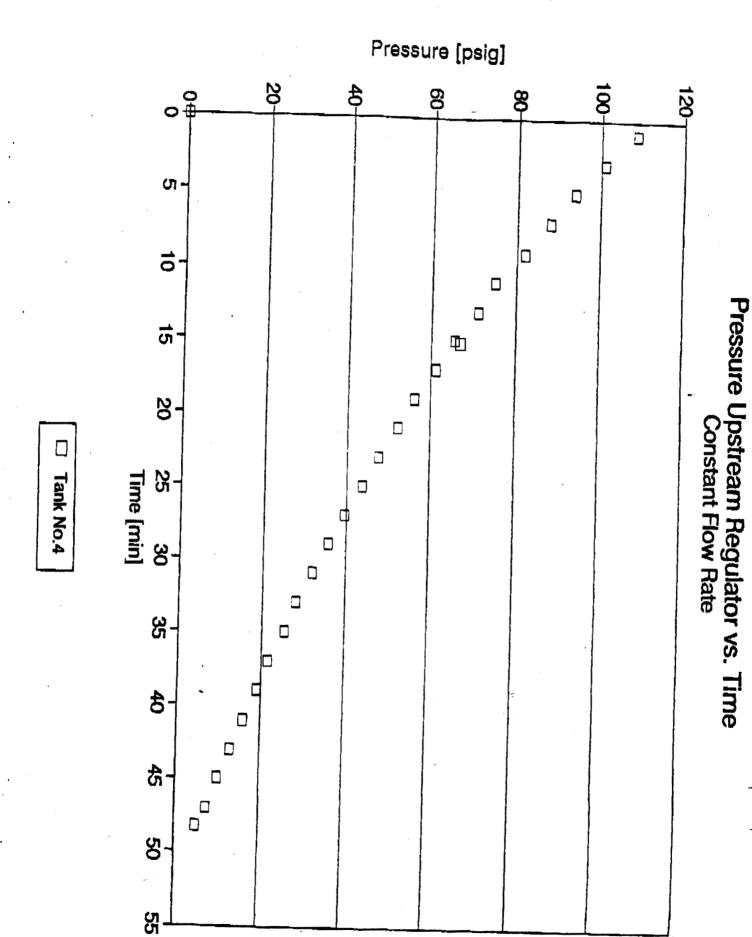
5.00

Propane weight

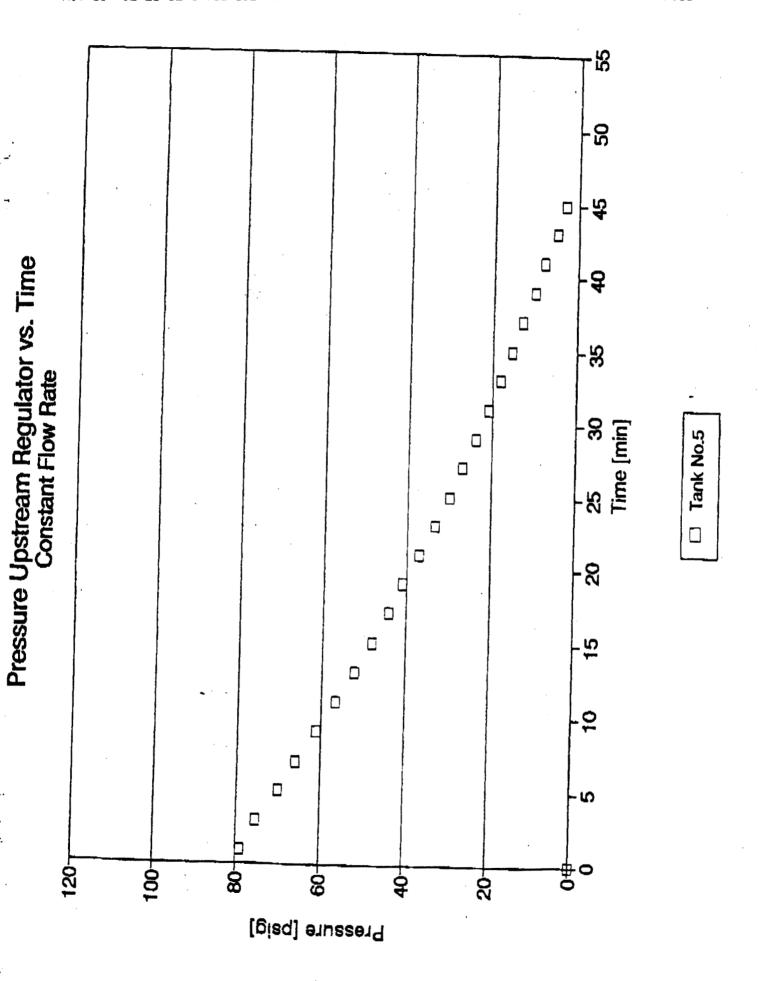
Tank No. 4

11.00 13.00 17.00 19.00 21.00 25.00 25.00

28.00 33.00 35.00 37.00 41.00 47.00 49.00



		43.00 45.40	39.00	33.00 35.00	29,00	25.00	19.00 21.00	15.00 17.00	11.00	7.00	3.00	+		Propers weight	File No. By
		3.00	10.00	18.00	27.00	30.00	41.00	48.00	56.50	70.00 66.00	79.00 75.50	(psi)	P upetr. Regul	7 \$	Saeflytech Corporati     N51163     Christoph Graumann
	è	7.80	7.80	7.85 7.90	7.85	7.80 7.80	7.80 7.80	7.85 7.85	7.80	7.50	7.30	lin" H2O]		: FB 000115 : 17 Jb : 7.0 lb	Saeflytech Corporation, Mr. Ron Fenton N51163 Title Christoph Graumann Date
-	7.90	8.00	8.00	8.00 8.00	8.00	8.00	8.00	8.00	8.10 8.10	8.10 8.10	0.00 8.10	in H2O]	ALL B Sheers	Tank weight in Test weight	n Femon Title Date
	0.83	0.64	0.65	0.64	0.61	0.59	0.58	0.54	0.54 0.54	0.57 0.55	0.60	Temp.Stream	7.	Tank weight initially (empty) feet weight	: Propane Tank Test
	0.27	0.30	0.34	0.36	0.40	0.45 0.43	0.48	0.53	0.58	0.64	0.65	Temp. Tank U	: 198.57	: 41 ab	wik Test
	-1.27 -1.36	-1.00 -1.00	-0.90 -0.90	62.0- 1800- 85:0-	-0.43 -0.50	0.26	0.04	0.00	0.26	0.44	[mV] 0.45		Ambient Pressure Ambient Temperature	Average Mass Flow	
	46.16 45.19	47.14	48.61	50.56 49.58	52.51 52.51	88 88 87 72	26 SS	58.88 57.89	61.30 60.33	83.75		7		Flow	
	26.30 31.29 35.77	-17.83 -17.83	<b>4</b> .36	3.10 -1.39	15.56 10.57	23.03 19.04	30.01	37.48	1.98		Temp.Ta	: 85 F	- ** 153203 lb/min : 772 mm Hg		Page:5
I.a	64.61 64.61	86.11	64.11 64.11	3 2 2 3 2 1 3	61.60 62.10	60.10	65.65 60.65			2083	(F)		<b>Vmin</b>		of:7



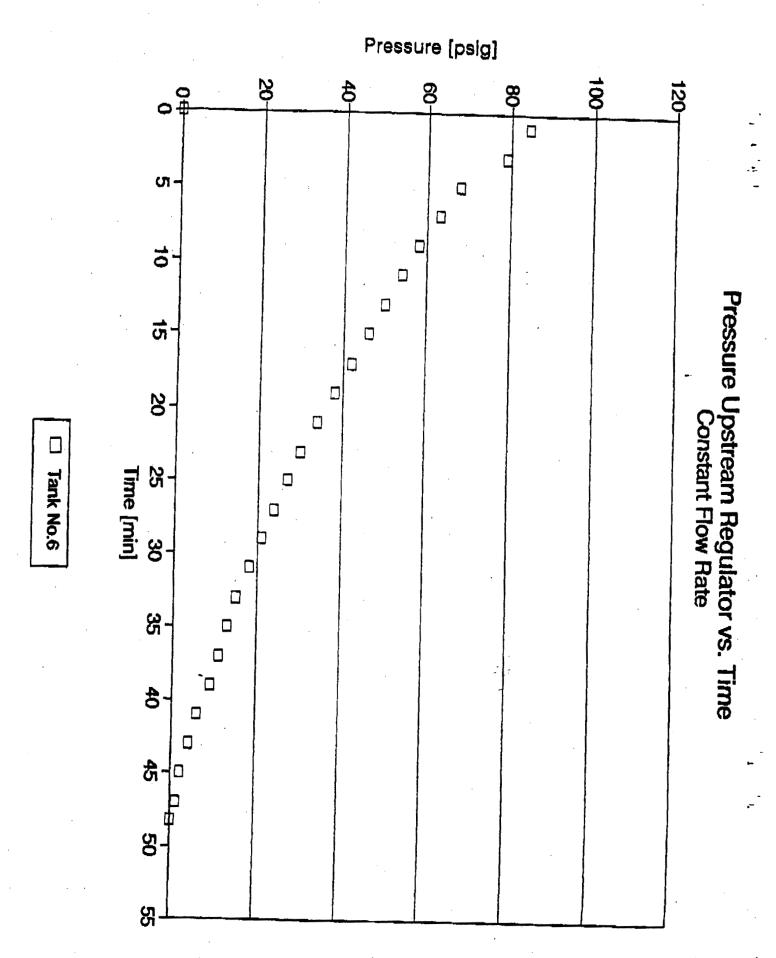
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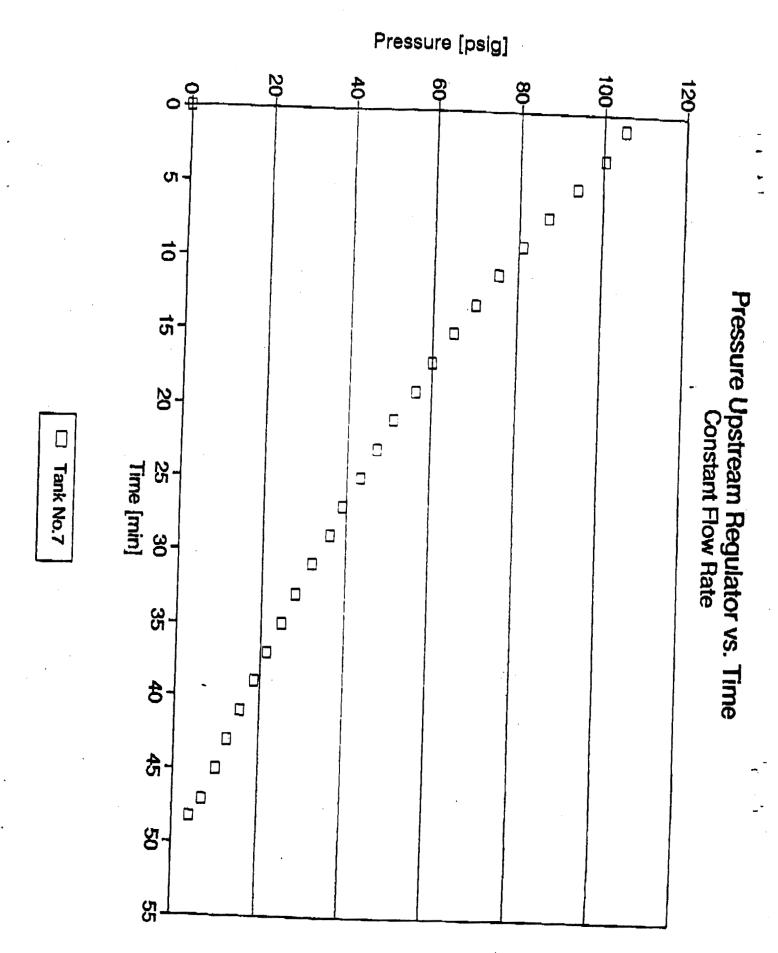
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AT-AT 484 =- -

<u>د</u>		-							
83.54	38.78	<b>44</b> .70	-1.42	0.26	0.00			<b>36</b> 23	* inappropriate data
23 11	39.26	1.21	-1.22	3.50	200	65	1.80	0,00	33.00
68.60	-39.26	2.23	3 2	200	0.62	2.00	210	0.00	2 2
62.50	3121	10.16	1 43	0.23	0.61	3.40	0.00	000	53.00
2.0	3 2	27.5	-1.39	0.24	19.0	7.00	3 6	1.00	51.00
3 3	30.28	44.70	-1.29	0.26	0.00	700	760	2.00	49.00
52 63	-26.80	45.19	-N. 1-	25.0	060	8.10	7.85	4.00	47.00
ଗ.10	21.R2	45.16	-1.00	0.27	0.59	8,00	7.85	0.00	13.00
60,60	-16.83	1000	300	029	0.58	8.00	7.65	8,00	45.00
00,60	-10,30	A5 67	<b>B</b> 20-	0.30	0.57	0,00	38.5	60.6	43.00
8.8	12 26	47.14	-0.91	0.31	76.0	8	7.宪	11.00	41.00
8	49.86	47.63	52	u.s.z	430	800	7.80	13.00	39.00
92.63	3.88	48.61	27.0	3	629	7.90	7.80	00.61	37.00
60,68	-0.39	95.Bb	3.6	0.34	0.55	7.80	7.30	10.00	3700
59.09	4.58	10,07	) ac	0.36	0.54	7.60	1.30	19.00	35.00
58.59	90.00	20.03	-0.55	0.37	0.54	/ 80	720	2100	33.00
30.08	808	50.56	0.48	0.38	0.53	78	730	24.00	31.00
90.00	12.07	51.54	0.45	0.40	20.00	7.60	7.30	27.00	29.00
57 50	15.56	52.51	0.33	24.0	0.50	7.60	7.30	30.00	27.00
57 09	20.54	53.49	0.23		051	7.60	7.30	34.00	25.00
57.09	23.53	54.47	6.17	0.20	0.50	7.50	7.30	38.00	23.00
56.08	28.51	\$4.82	0.07	0.46	0.50	7.40	7.30	42.00	21.00
56.08	31.00	56.42	20.02	0 40	0.48	7.30	7.05	46.00	00.61
56,08	33,99	37.40	200	0.50	0.48	7.30	7.10	00.00	1000
85.58	3/.48	20.57	0.04	0.52	0.48	7.30	7.10	91.00	17M
35.58	10.01	50 07	011	0.54	0.47	1.20	7.00	24.00	15.00
00.00	10.07	59.84	0.18	0.57	0.47	7.28	700.7	58.00	13.00
SE CO	55	60.33	0.28	0.58	0.47	720	7.00	63.00	11.00
80 82 80 80 82 80 8	88 CS	28.00	0.42	0.59	20.0	720	7.10	68.00	9.00
90.05	55,42	61.79	0.47	1970	0.54	740	7.00	<b>*79.00</b>	4.00
68.12	56.92	62.28	0.50	0.02	054	7.40	7.20	*84.50	1.00
7	Ŧ	Ξ			0.68	0.00	0.00	0.00	0.00
Temp. Streem	Temp. Iank Up Temp. Tank Low Temp.	remp. rank up	The state of the s	(mys)	[mV]	m" H20]	in H20)	psi	freezel
			Temp. Tank U Temp Tank I	Temp.Tank U	Temp.Stream	dp Orifice Plate Temp.Stream	p downstr. Regul.	or. negu.	
	. 42.7								Time
	. Eac		Ambient Temperature	: 197.26	7	Average BTU/hr.	al Arms		
	: 772 mm Ho	3	<b>Ambient Pressure</b>	20 20			. A 375 fb		Propens used
_	: 0.15227 lb/min	O.	Avorage Mass Flow		7 7 77	Test weight	: 17 lb	×	Miglaw erradorn
				• •	liziiv (empty)	Tank weight initially (empty)	: FB 000116		Tank No. 6
					: 22/10/1992	Date	al Anica yn	: Christoph Graumaryn	- Cy
of: 7	Page: 6			*Text	: Propane Tank Test	Title		NSI IOS	Die see
						Fenton	Careily and Comparation, Mr. Hon Feriton	· weiged o	
								- Cardinators C	Client



	50.38 2.0																												1,00 1,00 1,00 1,00 5,00 5,00 1,00 11	11.00 11.00	P upodr   [psi]   0.00   1.00   3.00   7.00   7.00   11.00   15.00   17.00   17.00   21.00   22.00   23.00   23.00 	11.00 12.00 11.00	11.00 12.00 11.00	11.00 11.00 11.00 11.00 11.00 11.00 11.00 11.00 11.00 11.00 11.00 12.00 21.00 21.00 21.00 21.00 21.00 21.00 21.00 21.00 21.00 21.00 21.00 21.00 21.00 21.00 21.00 21.00 21.00 21.00 21.00	0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.0	No. 7  Anno weight  Anno weight  1.00  1.0
	2.00 7.80	4.00 7.80	7.60	10.00 7.80	2.50 7.80	5.50 7.80	7.80					36.00 7.80	39.00 7.80		47.00 7.80	51.00 7.60	56.00 7.80	00.00	65.00 7.80	70.00 7.80	75.50 7.70		87.00 7.80	94.00 7.80	100.50 7.80	105.00 7.80	0.00		Regul. p downstr, Regul.		4 m				: FB 000172	
	7.60	8.00	8.00	8.00	8,00	8,00	8.00	8.00	8.00	8,00	8.00	8.00	8.00	8.00	8.00	8.00	8.00										-		L dp Orifice Plate Temp.Straam		Average BTU/hr.	i det weight	(Addres) American Manager Service	Tanala and Land Roy		Date
	063	063	080	080	0.61	0.61	0.60	0.59	0.59	0.58	0.57	0.56	0.55	0.54	0.50	051	0.50	0.40	0.47	0.45	0.45	044	270	0.44	0.46	C# 0	0.88	(mV)	Temp.Stream				(Application (Application)	[		: 22/10/1992
6.19	0.10	0.19	0 10	2	022	200	350	0.28	030	0.30	0.34	0.37	000	0.43	76.0	0.50	0.33	0.50	0.00	0.83	0.63	0.00	0.30	27.0	0.73	07.0		[mV]	Temp Tank U		204.68	: 63.25 B	46.5			
-0.08	5.8	-0.60	95.0-	70.0-	0.40	0.45	2 4	0.57	25.0	5 2	06.0	2.5	6.16	-0.10	-0.03	0.05	0.12	0.19	0.27	0.34	0.43	0.49	0.36	0.02	0.70	0.75	[Au]	Carlot and	1	Whitee months	American Tarmer	Ambient Pressure	Average Mass Flow			
5.30	40.79	41.28	12.26	43.23	44.21	44.70	40.08	10.00	47.63	10.01	50.07	51.05	52.51	53,49	54.96	56.42	57.89	59.35	61.30	6277	83.75	65.21	66.19	67.17	68.14	69.12	7					ã	Flow			
-1 89	-0.39	210	4.09	6.09	8.08	9.58	11.57	13.56	15.56	17.55	19.54	21.54	24.03	27.02	30.51	34.49	37.98	41.47	45.45	48.94	53,43	56.42	16.65	06.29	66.88	69.37	7	Temp. Tank Low		. 66 F	Full Hills year		: 0.15799 th/min			
32	63.61	63.11	69.11	නෙහ	62.60	01.23	61.60	61.60	61.10	60.60	60.10	65.65	59.09	58.09	57.59	57.09	86.38	55.58	80.55	54.58	54.07					68.62	[F]	V Temp. Streets					Ť			



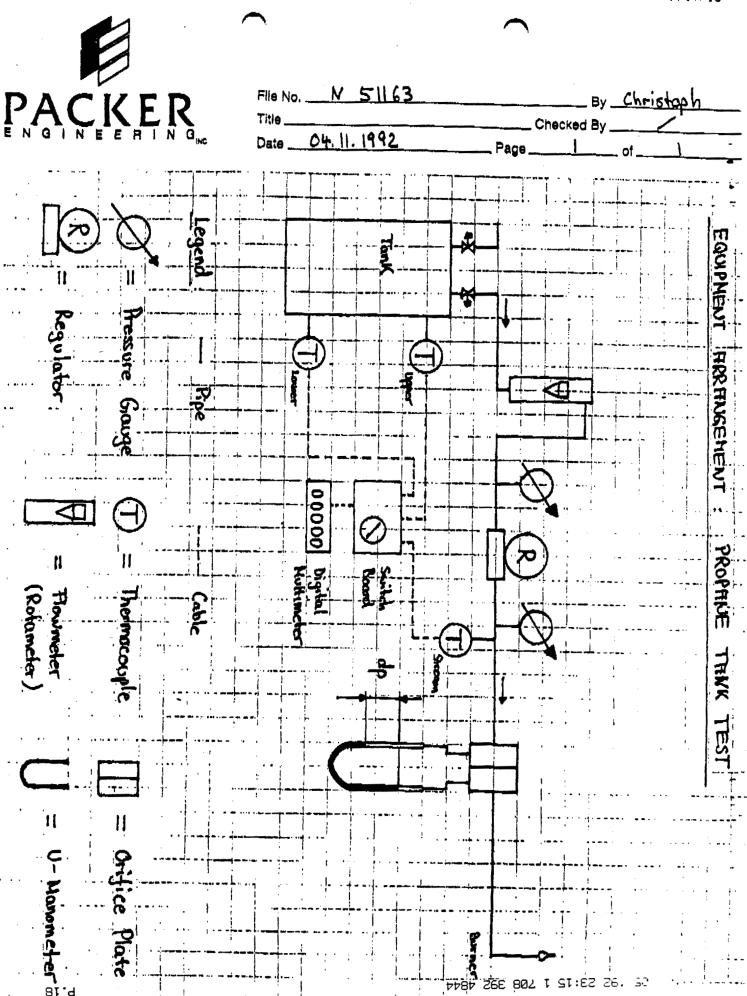




Figure 1 : Equipment Arrangement.

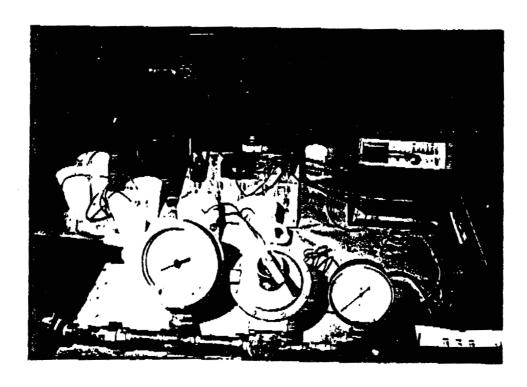


Figure 2: Temperature and Pressure Measurement Devices.



Figure 3 : Orifice Plate Unit and Propage Burning Torch.

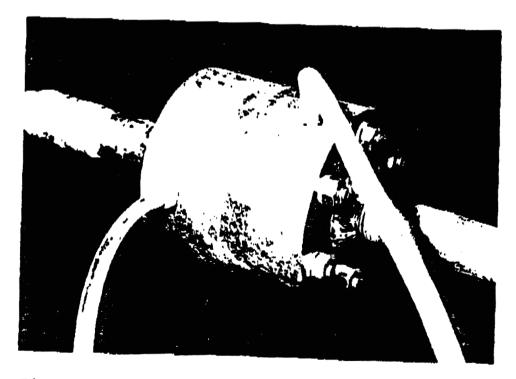
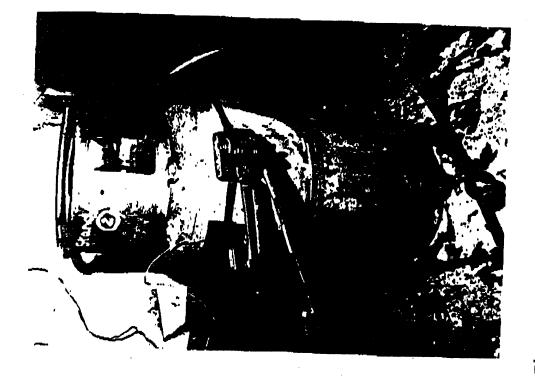


Figure 4 : Orifice Plate with Pressure Measurement Flange Tabs.



Pigure 6: Temperature Measurement at Lower and Upper Tank Surface Area.



Pigure 5: Measurement of Differential Pressure at Orifice Plate with an D-Manometer.

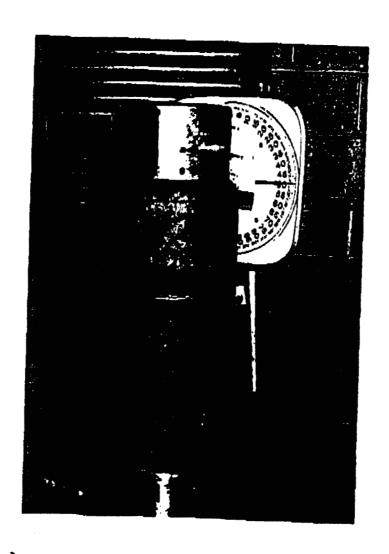


Figure 7 : Measurement of Tank Weight.